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ENGINEERING AND INDUSTRIAL EXPERIMENT STATION

College of Engineering

University of Florida

Gainesville

MOISTURE IN SURVIVAL SHELTERS

FINAL REPORT

ENGINEERING AND INDUSTRIAL EXPERIMENT STATION

COLLEGE OF ENGINEERING, UNIVERSITY OF FLORIDA

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OCD REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

ABSTRACT

An investigation was made into the sources of and the means of control of moisture in survival shelters.

Moisture was found to originate within survival shelters as a result of the metabolic process of the occupants and by evaporation from exposed wetted surfaces. The principal modes for introduction of moisture were found to be gross leaks in the shelter structure, vapor migration through permeable walls and the humidity contribution of the ventilation air.

Methods of moisture control included prevention of ingress by improved water and vapor proofing of the exterior shelter surfaces, removal by means of excess ventilation air, and condensation with or without subsequent rejection of the resultant latent heat.

No satisfactory methods or devices were found for condensing or absorbing water vapor when the resultant latent heat was liberated within the space to be conditioned. Both theoretical considerations and practical demonstrations indicated that the effective temperature was invariably raised thereby. Methods evaluated included absorption by treated fibers and by chemical agents as well as drying by mechanically powered dehumidification devices. ([illegible] AL-[illegible])

Water coils, employing cool water from constant temperature deep wells, were successful in condensing moisture from shelter atmospheres. Calculations indicate this method to be more efficient than cooling and dehumidification by compression refrigeration.

Integral mechanical or chemical dehumidifiers may be employed to produce and maintain satisfactorily low humidity environments in unoccupied shelters only if steady state water leakage and vapor migration can be kept to low levels. Otherwise, shelter and surrounding earth are raised to and maintained at temperature levels prejudicial to survival if the shelter must be used.

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SUMMARY

Under Contract OCD-OS-62-51, Subtask 1213A, an investigation was undertaken of the sources and the methods of control for moisture in survival shelters. Because the Contractor was simultaneously engaged in simulated occupancy tests of survival shelters under Subtask 1212A of OCD-OS-62-116, it was possible to test some methods and confirm some findings under simulated occupancy conditions.

Moisture Sources

These were found to consist of the metabolic contribution of shelter occupants and of evaporation from wet surfaces within the shelter as well as gross leaks in the shelter structure and permeable wall structures which permitted ingress of moisture from the shelter surroundings. Finally, the ventilation air which must be supplied to an operating shelter, both supplies moisture to and removes it from the enclosed space, the net effect depending on the interior and exterior environments.

The effect of wetted surfaces within the shelter was evaluated during a simulated occupancy test of a 100-person concrete block, semi-buried shelter. By wetting the entire floor during a period when the devices simulating occupants were inoperative, but when the shelter was being ventilated, the driving force for evaporation for this shelter could be evaluated. By applying the constants so determined to periods of time when the shelter was occupied (by simulated occupants), it was determined that the effect of the wetted floor was equivalent to an increase of from four to six percent of the designed occupancy.

It can be shown that wet shelter surfaces are not disadvantageous per se, but only as these surfaces evaporate moisture into the shelter atmosphere as a result of heat transfer from the shelter surroundings, rather than from sources within the shelter. Saturation of the shelter atmosphere as a result of evaporation of water within the shelter caused by utilization of shelter heat, actually lowers the effective temperature within the shelter.

Shelters should be made impervious to water infiltration and vapor migration during construction, as a later attempt to apply sealing coatings to inside surfaces is expensive and ameliorates rather than eliminates the problem.

Vapor migration through masonry walls was found to be significant in contributing to the humidity within shelters with this type of construction. A test conducted in a twelve person shelter demonstrated a steady-state vapor infiltration of from two to four quarts of water per day, when mechanical dehumidifiers of 1/3 and one horsepower were employed. Humidity within the shelter was maintained at the 45% and 20% levels respectively.

When the dehumidifiers were shut down, the shelter humidity rose sharply, indicating continued vapor migration. Had the larger dehumidifier been allowed to operate continuously, heat release equivalent to that of nine occupants would have been experienced. The shelter would have been kept in excellent "standby" condition with respect to humidity, but the thermal capacity of the surrounding earth would have been greatly prejudiced.

Methods of Control

Chemical Dehumidification - An effort was made to determine the effectiveness of chemicals as absorbers of moisture and the effect that such chemicals would have on environmental conditions within the survival shelter. Calcium chloride was studied rather extensively since this chemical has a greater affinity for moisture on a pound per pound basis than others of the desiccants which are commercially available. Theoretical studies indicated that while calcium chloride would absorb copious quantities of moisture, the absorption would increase the effective temperature, since sensible heat would be released due to the heat of hydration of the chemical and due to the latent heat of condensation of the water vapor. Thus, the end result of using desiccants on environmental control was disadvantageous. In fact, the theoretical study indicated that in any case where the work input to the dehumidifying device (the heat of absorption in the case of chemicals and the shaft work in the case of mechanical devices) and at least a portion of the heat of condensation, was not rejected to the outside atmosphere, an adverse effect on shelter environmental conditions would result.

Desiccants could possibly be used as a means for maintaining properly sealed shelters in a standby condition and would maintain low humidities which would prevent rust and mustiness in bed clothing and other damage associated with moisture to materials stored in the shelter.

Tests were conducted using simulated occupants and trays of calcium chloride and these tests bore out the results which were predicted by the theoretical study.

Mechanical Dehumidification - Actual tests were not conducted using a mechanical dehumidifier while measuring changes in effective temperature under occupied conditions. However, a theoretical analysis indicated that they would have an adverse effect on shelter environment. Tests were conducted using mechanical dehumidifiers as a means of drying out shelters and maintaining shelters in a standby condition which indicated that they would be effective in this respect. In climates where these devices would operate in ambient temperatures of less than 65 F, it would be necessary to establish means of defrosting the evaporator coil of the dehumidifier on a

periodic basis. This was accomplished, on the unit tested, by locating the sensing element of a thermostat, where it could "see" (in a radiation sense) the evaporator coils as they frost This might also be accomplished with a time switch or by means a valve which would reverse the function of the evaporator and condenser and be triggered by low suction pressure.

Dehumidification with Excess Ventilation Air - The simples method of absorbing moisture and removing it from the shelter i the use of excess ventilation air assuming that ambient air has the ability to absorb moisture in the shelter space and is avai able at a temperature suitable for cooling the shelter space fo a major portion of the typical day.

Dehumidification with Well Water - Assuming that a plentif supply of relatively cool ground water (72 F or less) is availa it is possible to control shelter environment by means of circu ting water through a coil and passing shelter air across this c Experiments conducted indicate that 72 F water will maintain sh ter conditions at or near the comfort zone and that approximate one pound of water is required for each 3.4 Btu absorbed when t shelter temperature is about 82 F.

Dehumidification by Means of Closed Cycle, Refrigeration Equipment - No tests were conducted using air conditioning equi ment since manufacturer's data is quite complete with respect t the availability and capacities of such equipment as well as th power requirements of such equipment. In general, 1 kilowatt h of electrical energy is needed to remove 12,000 Btu from the co tioned space per hour and a power requirement of this magnitude would necessitate auxiliary generating equipment, since it is n likely that the public utilities could be relied upon to supply power during an all-out atomic attack and the period of fallout that would follow such an attack. It may be assumed that in th average shelter 1 kilowatt of electrical energy could be utiliz to furnish a cooling effect to satisfy the needs of 20 occupant Air conditioning systems were considered the most expensive and the most complex of any system studied and also the most effect However, the cost and complexity would make such systems suitab only for large, community-type shelters.

Power Systems - Since all of the dehumidification devices that were studied require a source of power for operation, it was necessary to investigate the power requirements of each dehumidification system and compare these requirements with the available sources of power. Available sources of power were muscular effort of shelter occupants, storage batteries, and internal combustion engines, either direct drive, or coupled with electrical generators. It was determined that the muscular power of occupants was adequate for heat and moisture removal, but left little margin for safety in the event that the occupants became even slightly incapacitated by illness. Storage batteries were found to be expensive, needed additional

equipment to maintain a charge, contained acids, and generated combustible gases during the charging process. In fact, the fixed charges on sufficient storage batteries to meet the needs of the shelter would be sufficient to cover the cost of an auxiliary internal combustion power unit.

Of all the power systems studied, diesel powered generator sets were found to be the most suitable for use in shelters from every respect with the exception of first cost. Units of this type have a high degree of dependability, fuel may be stored for long periods without deteriorating, dangerous fire hazards were practically nonexistent and the products of combustion while containing odorous gases, were not toxic. Such units are available in air cooled models which would remove the difficulties associated with freeze up and corrosion that would exist in water cooled units.

I. INTRODUCTION.

Statement of Problem. Experimental work, the results of which are presented in this report, was conducted in support of Contract No. OCD-OS-62-51, Subtask 1213 A, which was awarded to the Engineering and Industrial Experiment Station of the University of Florida, on February 3, 1962. Article I - Scope of Work, of that contract states:

"The Contractor, in consultation and cooperation with the Government, shall, in accordance with proposal of 12 December, 1961, furnish and supply professional services to evaluate various methods and to develop instructions for procedures and specifications for economical equipment to prevent excessive humidity and moisture condensation in shelters.

Methods considered or devised shall include those which do not as well as those which do require power or heat. This will include, but is not limited to the following:

1. Study sources of moisture and condensate in occupied and unoccupied shelters, including the effects of climate, ground water, permeability, ventilation, latent heat, dew point and surface temperatures.

2. Investigate promising methods for reducing humidity and preventing moisture condensation.

3. Evaluate commercial dehumidifying apparatus for shelter use and devise simple procedures to mitigate conditions due to excessive moisture.

4. Perform required comparative tests and prepare recommendations and specifications for low cost apparatus or procedures.

General Procedure. Much of the investigation pursued the classical approach of literature survey, theoretical investigation, laboratory or pilot-scale study, and full scale application. There were occasions however, when little or no information could be found to indicate previous work. Similarly, it was deemed expedient at times to proceed directly to a full-scale test, bypassing the construction and evaluation of laboratory scale apparatus.

It was fortunate that a second investigation associated with survival shelters, Contract No. OCD-OS-62-116, was being pursued at the same time. Because of this circumstance, equipment and personnel were made available on a scale that might otherwise have been unwarranted. In particular, the full-scale simulated occupancy tests were made economically possible because they could be appended to similar tests required by Contract No. OCD-OS-62-116, Subtask 1212 A.

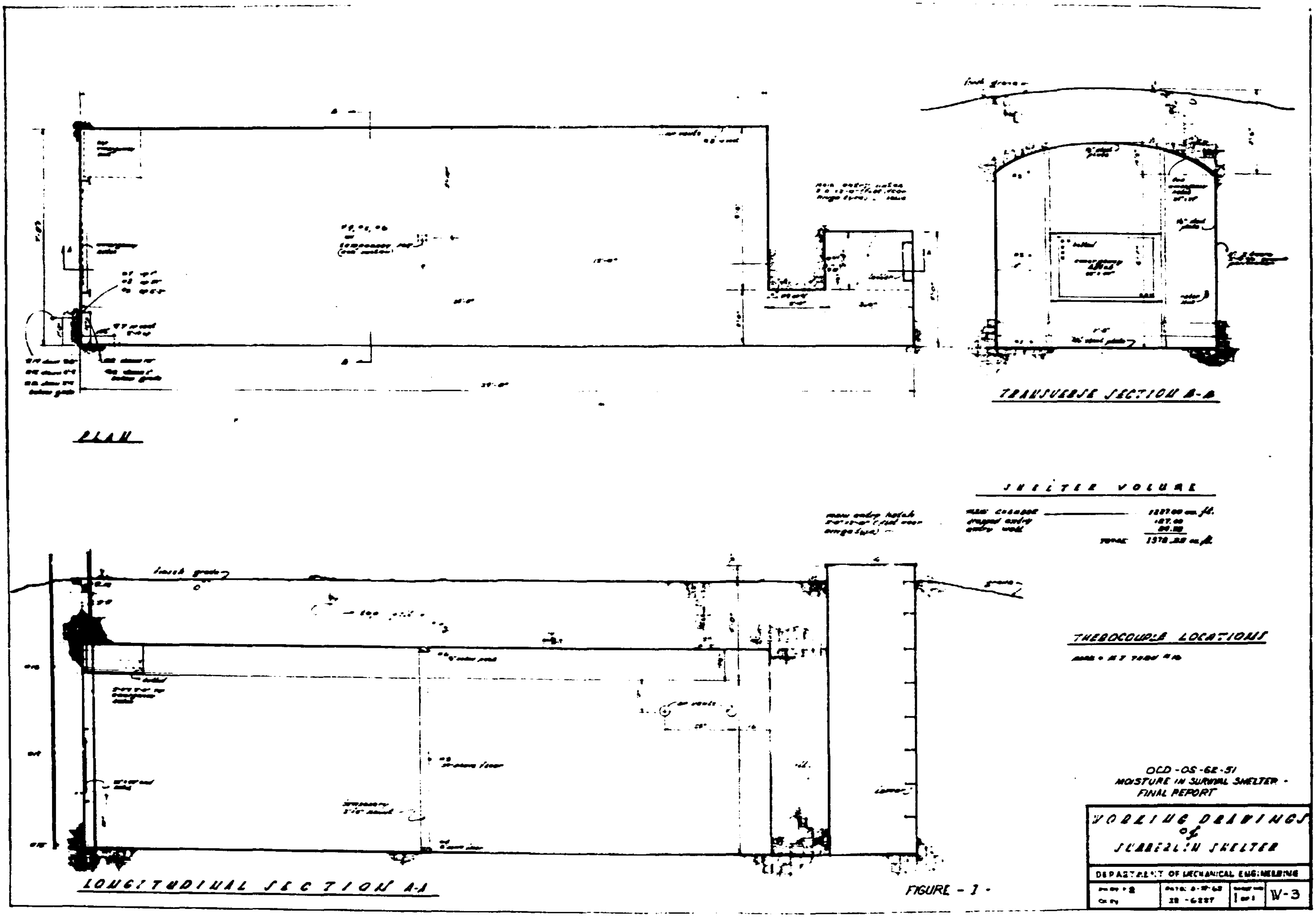
In addition to other items described in more detail in appropriate individual sections, two major classes of experimental equipment were used in more than one phase of this investigation. They were a group of four actual survival shelters, and two different types of simulated occupants, which allowed realistic tests of the shelters to be made.

The four shelters which were utilized are shown in Figures 1 through 4 inclusive. They ranged in size from the smallest, with a nominal capacity of twelve persons, to the largest with a capacity of 250 persons, both figures being based on an assignment of ten square feet of floor area per person. In order of their utilization, they were: the Summerlin shelter, a completely buried, welded tank structure with a capacity of eighteen persons, the Broyles shelter, of concrete block construction with all block voids filled, semi-buried and with a capacity of twelve persons, the Napier shelter, a 100 person community shelter of concrete block construction, with only about 10% of the block voids filled and the Central Stores basement, a "designated area" shelter in an existing building, consisting of a basement room in a two story reinforced concrete building.

The simulated occupants utilized were devices which, when supplied with electrical energy, produced water vapor and sensible heat in the amounts that would have been produced by metabolic processes in humans. Two types of simulated occupants subsequently referred to as "Simocs" were employed. The first, patterned after a design of the Mechanical Section, U. S. Bureau of Standards, was a cylindrical sheet metal structure about four feet high, covered with an absorbent toweling. Water dripped onto the conical head of the device, wet the cloth, and was subsequently evaporated by the action of a controlled heat source in the base of the apparatus. The other type of "Simoc" was the product of the Mechanics Research Division of the General American Transportation Corporation. It consisted of a high speed disc which atomized water and a fan to mix this mist with warmed air from a high capacity variable power heater. This latter device could simulate from five to fifty occupants by variation in water flow and power settings, while the sheet metal cylinders could each only simulate one person. In the case of both "Simocs", the relative proportions of the latent heat and sensible heat could be adjusted to agree with the known metabolic variation of this ratio with ambient temperature.

<u>Presentation of Results.</u> The material which follows is presented under five main headings. A study is first made of <u>Moisture Sources Associated with Survival Shelters.</u> This is followed by a section entitled, <u>Integral Dehumidification Methods and Devices</u>, in which a fundamental fallacy about such devices is discussed. A section follows on <u>Environmental Control Methods and Devices with External Heat Sink</u>, in which it is shown that this

approach offers several practical methods of controlling humidity. A comparison of several proposed control methods is made in the section, Power Requirements for Environmental Control. Formal Conclusions are disclosed in a section with that title, but are also presented more briefly in a Summary which precedes the report proper. Finally, data which were regarded as too bulky for the body of the report, is presented in tabular form in an Appendix.


PLAN
TRANSVERSE SECTION B-B
SHELTER VOLUME
THERMOCOUPLE LOCATIONS
LONGITUDINAL SECTION A-A
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WORKING DRAWINGS
of
DEPARTMENT OF MECHANICAL ENGINEERING
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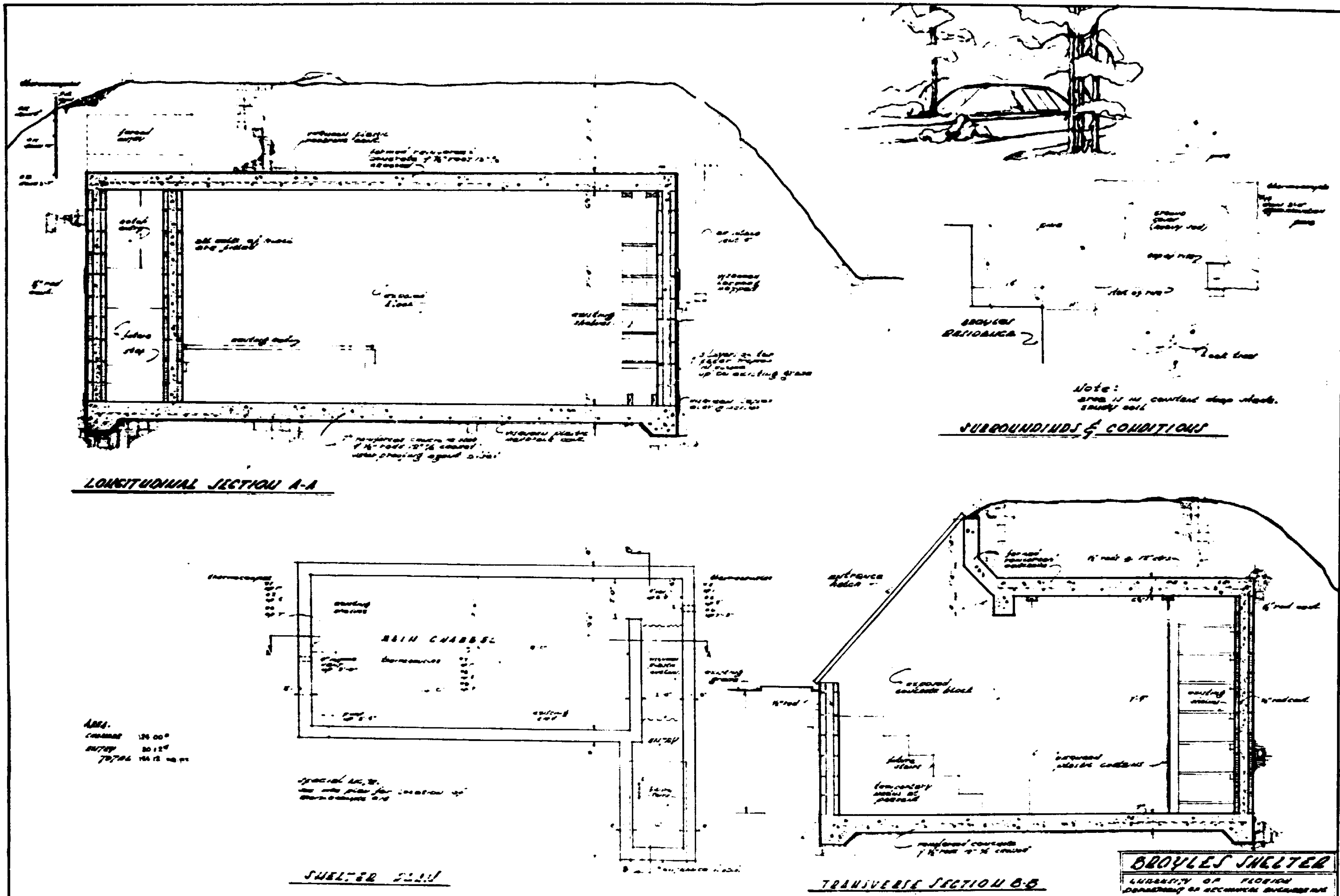
FIGURE - 1 -



· FIGURE - 2 ·

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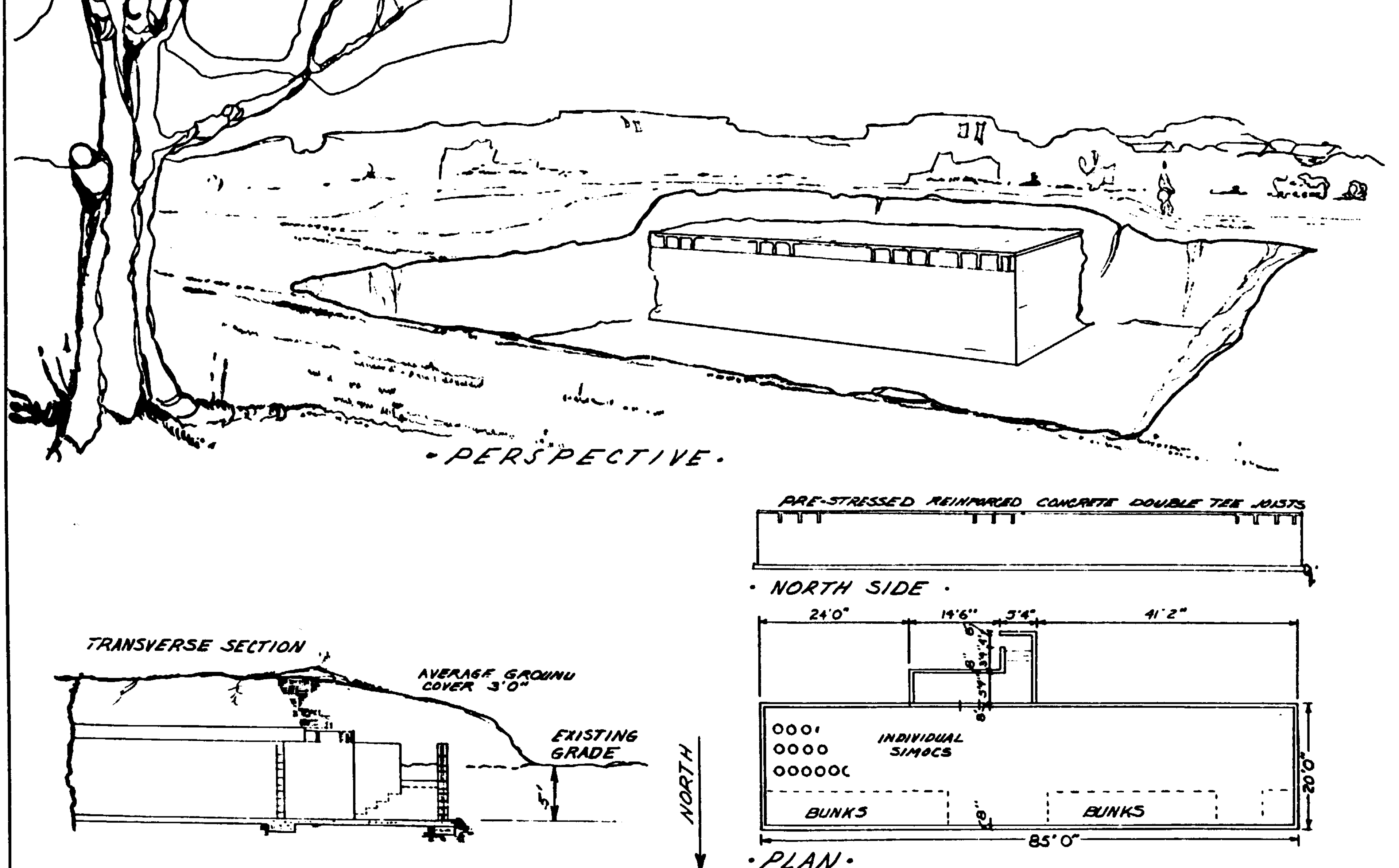
NAPIER SHELTER



• FIGURE • 3 •

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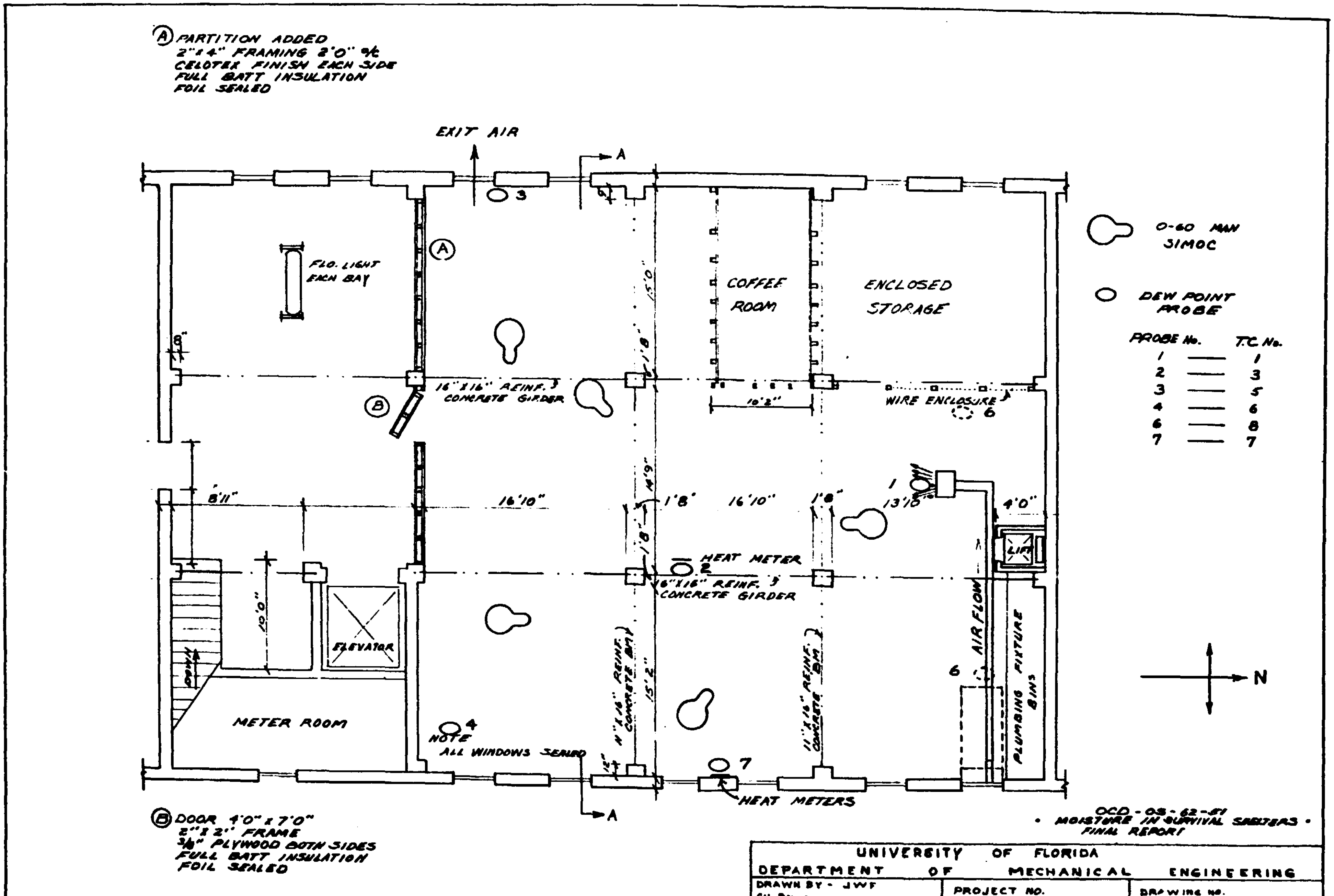

Ⓐ PARTITION ADDED
2"x4" FRAMING 2'0" o/c
CELOTEX FINISH EACH SIDE
FULL BATT INSULATION
FOIL SEALED
EXIT AIR
FLO. LIGHT EACH BAY
COFFEE ROOM
ENCLOSED STORAGE
16"X16" REINF. CONCRETE GIRDER
WIRE ENCLOSURE
16'10"
1'8"
16'10"
1'8"
13'10"
4'0"
8'11"
10'2"
15'0"
14'9"
15'2"
10'0"
HEAT METER
16"X16" REINF. CONCRETE GIRDER
11"X16" REINF. CONCRETE BM.
ELEVATOR
LIFT
AIR FLOW
PLUMBING FIXTURE BINS
METER ROOM
DOWN
NOTE
ALL WINDOWS SEALED
HEAT METERS
0-60 MAN SIMOC
DEW POINT PROBE
PROBE No. T.C. No.
1 — 1
2 — 3
3 — 5
4 — 6
6 — 8
7 — 7
N
Ⓑ DOOR 4'0" x 7'0"
2"x2" FRAME
3/8" PLYWOOD BOTH SIDES
FULL BATT INSULATION
FOIL SEALED
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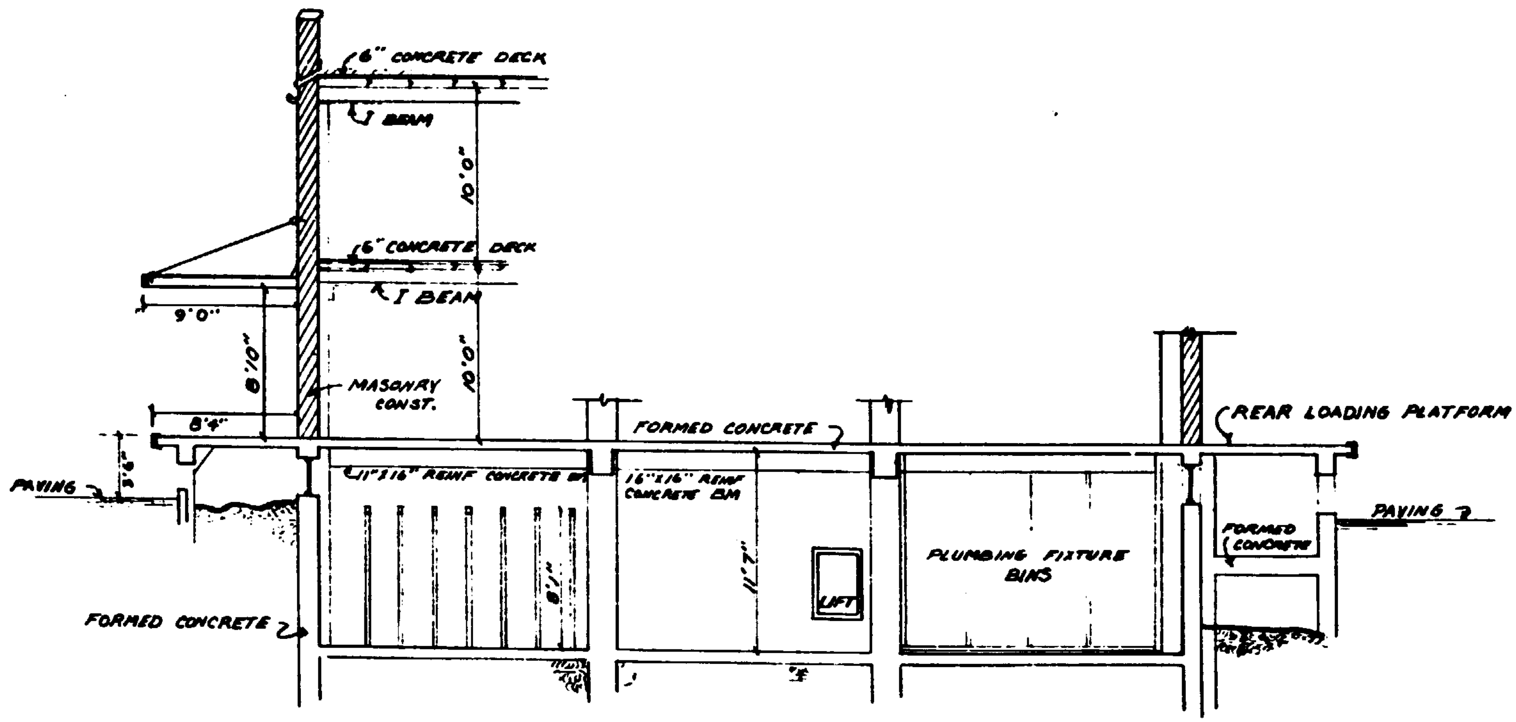
DEPARTMENT OF MECHANICAL ENGINEERING
DRAWN BY - JWF
CH BY -
DATE - 10-3-62
PROJECT NO.
IR-6227
DRAWING NO.
W-10
REVISIONS
DATE
TEST SHELTER No 4
CENTRAL STORES

• FIGURE - 4·A •



SECTION A-A

FIGURE - 4-B

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UNIVERSITY OF FLORIDA DEPARTMENT OF MECHANICAL ENGINEERING		
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REVISIONS DATE		TEST SHELTER No 4 CENTRAL STORES

II. MOISTURE SOURCES ASSOCIATED WITH SURVIVAL SHELTERS

Water Leakage in Shelter Areas. Leakage of water into shelter areas may be evaluated from at least three standpoints, radiological effects, psychological effects and physiological effects. This investigation has been concerned only with physiological effects and then only to the extent that exposed wet surfaces may contribute moisture to the ventilation air, and thereby alter the effective temperature. In a similar vein, the reasons why water leakage occurs, and its prevention might be the subject of considerable speculation and/or investigation and a great deal might also be said about details of shelter construction. These matters were not subjects of this investigation. It may be pointed out, however, that 17 shelters have been subjected to simulated occupancy tests in connection with Contract OCD-OS-62-116, Subtask 1212 A. Table I (Appendix) lists types of leakage noted, which may be summarized by saying that 12 of the total showed evidence or had histories of leakage, faulty plumbing or piping, or flooding due to submersion of entranceways below the level of outside water.

In view of the above, it was deemed advisable to investigate the effects of wetted surfaces which might result from leaks. This was done during a simulated occupancy test of the Napier Shelter, a 100-person, semi-buried structure, shown in Figure 3. The entire floor of the shelter was covered with a thin layer of water. The simulated occupants were made inoperative, while the shelter ventilation was continued at its nominal rate of 6 cfm per occupant and summer conditions of temperature and humidity.

During a four and one-half hour period* which was considered representative, the temperature of the floor and water film averaged 85.85 F. The average water content of the ventilation air was 0.0184 pounds of water per pound of dry air, and that of the exhaust air, 0.0232 pounds of water per pound of dry air. These values permitted evaluation of the constants C and A in the mass transfer equation:

$$\frac{dM}{d\theta} = CA\,(P_s - P_a)$$

Where: $dM/d\theta$ = rate of evaporation of water, lb/hour

C = constant, typical of particular shelter

A = wetted area, ft^2

P_s = saturation vapor pressure of water film on floor at floor temperature, lb/in^2

P_a = partial pressure of water vapor in ventilation air, lb/in^2

* Data taken from Table II - Appendix

The values to be used became:

$$\frac{dM}{d\theta} = \frac{(\text{water pickup})}{(\text{lb dry air})}\ (\text{lb dry air}) =$$

$$= (0.0232 - 0.0184)\frac{(600\ ft^3)(1\ lb)}{(\ min\ )(14.3\ ft^3)} = 0.2013\ lb/min$$

$$= 12.07 \text{ pounds per hour}$$

P_s = 0.6123 lb/in^2 @ 85.85 F

P_a = 0.418 lb/in^2 @ specific humidity of 0.0148 lb H_2O/lb air

Substituting:

$$12.07 = CA(0.612 - 0.418)$$

$$CA = 12.07/0.194 = 62.1$$

The mass transfer equation was then reapplied, this time to the Napier Shelter during the actual simulated occupancy test. The data for this test is presented as an Appendix to, "Simulated Occupancy Test - Napier Shelter," OCD-OS-62-116 - August 24 - September 10, 1962, Engineering and Industrial Experiment Station, University of Florida, Gainesville, Florida. From these data the following averages have been computed:

	Period	Dew Point of Shelter Air (P_a, lb/in^2)	Floor Temperature, ^oF (P_s, lb/in^2)
#1	1200 - 8/24 to 1200 - 8/26	79.96 F, (P_a = 0.507)	80.80 F, (P_s = 0.520)
#2	1200 - 8/29 to 1200 - 8/31	84.98 F, (P_a = 0.596)	84.96 F, (P_s = 0.596)
#3	1200 - 10/6 to 1200 - 10/7	85.72 F, (P_a = 0.610)	86.71 F, (P_s = 0.629)

During Period 1, the ventilation rate was 3 cfm/occupant and the shelter air was being cooled by a cold water coil. Had the entire floor been wetted, the evaporation effect would have been

$$\frac{dM}{d\theta} = CA\ (P_s - P_a) = 62.1\ (0.520 - 0.507) = 0.807\ lb/hr$$

For Period 2, the effect would have been zero, since the driving

force for vaporization disappeared as the floor reached the dew point of the adjacent air. It may be noted here that during Period 2, the ventilation rate was 6 cfm/occupant and there was no supplemental cooling.

During Period 3, the ventilation rate was increased to 8 cfm/occupant (no supplemental cooling) with the result that:

$$\frac{dM}{d\theta} = 62.1\ (0.629 - 0.610) = 1.18\ \text{lb/hr}$$

In terms of equivalent occupants, during Period 1, the wetted floor would have had the effect of four and one-half additional persons, there would have been no effect during Period 2, while during Period 3, the additional loading imposed by the wet floor would have been equivalent to that of six and one-half additional occupants. In terms of areas, the wetted floor contributed the equivalent of one occupant for each 378 square feet of area during Period 1 and one occupant for each 262 square feet during Period 3.

The driving force for evaporation is the difference between the vapor pressure of water at the temperature of the wetted surface, and the partial vapor pressure of water in the adjacent air. Figure 5, which follows, evaluates this driving force for a typical range of floor temperatures, temperature differences between floor and air, and relative humidities of the ventilation air. It can be seen that the driving force, ΔP, varies directly as the floor temperature and inversely as the temperature difference between floor and air. A few of the family of curves for a temperature difference of one degree have also been plotted to show the effect of changes in the relative humidity of the ventilation air and it can be seen that the driving force varies inversely with relative humidity as might have been expected.

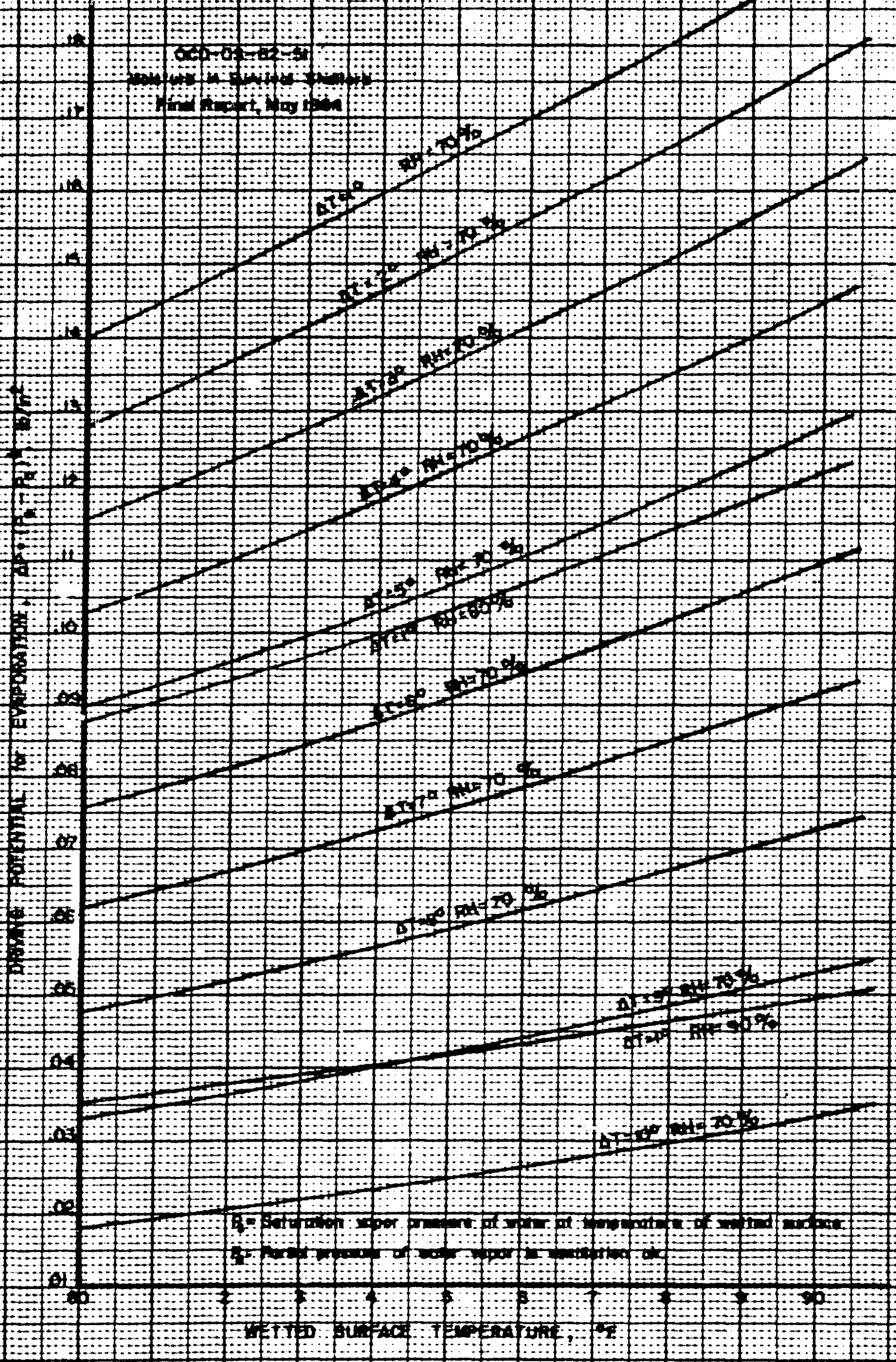

Fig. 5 EVAPORATION FROM WETTED SURFACES

The question might be raised at this point as to the significance of the effects just discussed. It must again be pointed out that the authors cannot evaluate the psychological effects of wetted floors, walls or ceilings, which may be minor or overriding with respect to any other considerations. From the standpoint of its effects on the shelter environment, however, some conclusions may be drawn.

Any moisture which is evaporated into the shelter environment as a result of heat transfer from the shelter surroundings, increases the effective temperature within the shelter, and hence is disadvantageous, moisture which is evaporated as a result of heat transfer from within the shelter proper results in a reduction of effective temperature and hence is advantageous. The limit of such advantageous evaporation is reached when the total moisture in the shelter exhaust air reaches the saturation value at the exhaust temperature, and hence is a function of shelter loading and ventilation air properties. Since the air adjacent to the wetted surfaces is, in general, warmer than the surfaces, the heat transfer will normally be from the air to the water film, thus resulting in advantageous evaporation. Should the dew point temperature of the air reach an equilibrium with the wetted surface temperature, no evaporation will result. When the dry bulb temperature of the air is below the wetted surface temperature, evaporation will take place and will result in heat transfer from the surface to the air. This heat loss is then made up by transfer from the shelter surroundings, wall, earth, etc., with the result being a net increase in the enthalpy of the shelter air, and hence an increase in effective temperature. It may also be pointed out that when a wetted surface is evaporating moisture into a shelter enclosure, this surface may be partially or totally removed from participation in heat transfer from shelter to surroundings, because of the reduction in surface temperature.

Many suggestions to ameliorate condensation and dripping, have been advanced by persons interested in the research on moisture problems. Two such proposals are worthy of discussion here. The first involves sloping the shelter ceiling at such an angle that condensate droplets merge into streams and run along the ceiling to its juncture with the walls, rather than dropping individually from the droplet's point of origin. A graded peripheral gutter at floor level would conduct the condensate to a sump for utilization or disposal.

A second proposal envisions a false ceiling of plastic sheeting or similar material coupled with furred wall panels, behind which air could circulate and preferentially deposit moisture.

The authors find no fault with proposals similar to that outlined first above, which attempt only to direct condensate into a favorable flow pattern after its formation. and without in any way impeding the normal circulation of air. The second

scheme however appears to have objections, in that any such interior structures, designed to channel air flow, must of necessity impose some frictional resistance to air flow. As will be shown in a later section on chemical dehumidification, natural drafts due to density differences cannot be depended on to produce air movements in the special case where the air is losing both heat and moisture. Under these conditions, changes in density nearly cancel each other out. In addition, any barrier interposed between the shelter walls and the shelter occupants reduces the possibility of heat loss by radiation, and hence limits the capability, as a heat sink, of the earth surrounding the shelter.

If ample power for ventilation may be assumed, the false ceiling-furred wall concept is quite possible. The ventilation air would be introduced near the middle of the shelter and would exhaust into the space between shelter walls and false panels. Some condensation could take place along with heat transfer to and through the shelter walls. If still more power can be postulated, the complexities of ventilated wall and ceiling false spaces may be eliminated. Walls and ceiling would be furred out and covered with appropriate panelling, but the spaces so produced would not become part of the path of the ventilation air. The shelter-side surfaces of this panelling would thus be partially insulated from the cold walls and condensation would be prevented. Obviously, some loss of heat transfer through the walls would result, and a greater quantity of ventilation air would be required to carry away the heat generated within the shelter. Should this approach be adopted, the panelling should be readily removable in the event of a ventilation power shortage or failure.

Water Leakage, Corrective Methods. Following the "wet floor" tests just described, which simulated the effect of very severe leakage, an evaluation of the actual leakage was made and attempts made to reduce its magnitude by applying commercially available waterproofing materials. Since the ground around and over the shelter was dry at the time, the effect of a soaking downpour was simulated by flooding a shallow trench in the earth fill over the north wall of the shelter (see Figure 3). This procedure developed several new leaks in the roof structure, but also produced the same effects in the interior of the shelter that had been earlier noted following heavy rain. These effects were a series of leaks in which the flow of water was actually visible, along the juncture between the north wall and the floor, and a damp wall extending upward from the floor for about thirty inches and terminating in an irregular, but very definite "water line." These experimentally controllable "leaks" were treated with three types of materials advertised as appropriate for the conditions described. The products used consisted of a crack filler and two materials for application to wet walls. None was completely successful, although applied with what was believed to be strict adherence to the instructions accompanying the product.

The crack-filler, a cement like material, was found to have only a very short useful period after mixing during which it could be applied. If used before it had developed some initial "set", it was forced out of the cracks by the outside hydrostatic pressure. If application was delayed as much as a minute too long, the material had hardened to such an extent that it could not be forced into the cracks. The result was that only twelve to eighteen inches of leaking crack could be treated with any one batch of mixed material. As a consequence, results were not uniform, and while it was felt that there were some few regions in which the treatment was successful, there were many more in which seepage continued unimpeded.

Next an attempt was made to reduce or eliminate the seepage through the walls. In the area to be tested, the walls were damp to the touch and discolored for a distance of about thirty inches up from the floor. Whether this represented the actual level of the outside water table, or whether water was being carried up within the pores of the blocks by capillary action, was not ascertained. The area to be treated was further wet down (as required by application instructions) and a band of waterproofing material about four feet high was painted on and this was followed by the required second and third coats. For these latter treatments, only portions of the previously treated areas were covered, in order that the efficacy of one, two and finally three coats could be tested.

Two types of material were tested. One was a mixture of finely ground iron powder, Portland cement and a rusting agent.

The descriptive material accompanying this product indicated that the cement and iron particles were intended to penetrate pores of the wall where rusting caused an expansion of the iron so that the pore was solidly filled. The second material had a similarly described physical action, but was stated to be entirely of a cementitous nature.

After the materials had cured for the required period, the ground outside the wall was again wetted and an evaluation made. There was no dramatic reduction in seepage by either material at any of the three levels of treatment. The "water line" on the wall could be traced uninterruptedly from untreated wall, over wall that had one, two, or three coats of material. The line was most visible in the case of the iron waterproofing, but this was believed to be largely due to the greater color change from dry to wet as compared to the brilliant white surface produced by the all cementitious compound. The latter however, was still as wet as the adjacent untreated wall, as was proved by its ability to quickly wet tissue paper.

A sales representative of the company from whom the iron waterproofing had been obtained, examined the experiment and recommended additional coats be applied. This was done, again in such a way that the incremental value, if any, of each additional coat could be evaluated. Unfortunately, just at the time the wall was ready for testing again, the Cuban crisis intervened, and the shelter was re-occupied by its owners who, in the course of their preparations for use, painted the interior wall surfaces with conventional materials. Since that time, there has been no evidence of leakage through the walls, but this is attributed to dry weather rather than any virtue in the paint used.

It is difficult to draw conclusions from the test of waterproofing compounds. The proponents of the materials, both in their printed advertising, and in personal interviews are positive that their product has stopped similar leaks and seepage in the past and they are certain that a survival shelter offers no unusual or insurmountable problems. Construction men on the other hand, take a very skeptical attitude toward application of waterproofing on the <u>inside</u> of a structure, to prevent water infiltration from the <u>outside</u>. Probably the correct evaluation lies somewhere in between. The authors of this report conclude that the application of the materials tested did <u>not</u> stop seepage through a concrete block wall, although made in accordance with instructions on the container labels.

Vapor Migration Through Walls. As mentioned in the preceding section, the best waterproofed concrete block shelter, even though it had only one small leak (which was visible during periods of heavy rainfall) still permitted water vapor to penetrate the walls. This contention is based on the results of a dehumidification experiment and the results are presented in graphical form in Figure 6. From this plot of ground and shelter temperatures, effective temperature, relative humidity and moisture removal, several conclusions can be drawn.

When the experiment began, the temperature and humidity within the shelter were those of a typical semi-buried shelter under local winter conditions. The 90% relative humidity condition had forced the shelter owner to remove all bedding and canned goods to prevent mold in the one case, and rust in the other. A Westinghouse 1/3 horsepower mechanical dehumidifier was installed. The shelter entrance was closed and covered loosely with a plastic membrane. In a period of ten days (February 26 to March 8) the relative humidity dropped to 45% and the dry bulb temperature rose five degrees. Both of these values leveled off and remained relatively constant for the period from March 8 to March 27.

It is assumed that the period from February 26 to March 8, represents a drying out of the concrete blocks, and that the falling rate portion of the water removal curve represents an approach to equilibrium. The second period from March 8 to March 27, is surmised to represent a dynamic equilibrium between the capacity of the dehumidifier and the rate of vapor migration through the waterproofing materials on the exterior of the shelter. Exterior ground temperatures were taken, and it is believed that they were low enough and stable enough so that the heat released within the shelter was being removed at constant temperature by conduction. This heat would amount to the motor horsepower, plus the latent heat of the 2.2 to 2.4 liters of water being condensed per day. The actual power consumption of the motor was 3.4 amperes at 115 volts, or 391 watts, so that the heat output was:

$$\frac{(391\ \text{watts})}{}\frac{(3.413\ \text{Btu})}{(\text{hr})}\frac{(24\ \text{hr})}{(\text{watt})}\ \frac{}{(\text{day})} + \frac{(2.3\ \text{liters})}{(\text{day})}\frac{(1000\ \text{gm})}{(\text{liter})}\frac{(1\ \text{lb})}{(454\ \text{gm})}\frac{(1055\ \text{Btu})}{(\text{lb})}$$

$$(391)(3.413)(24) + \frac{(2.3)(1000)(1055)}{454} = 32{,}000 + 5340 = 37{,}340\ \text{Btu/day}$$

Considering the total inside area of the shelter of approximately 600 square feet, estimated heat transfer amounts to:

$$\frac{37{,}340}{(600)(24)} = 2.59\ \text{Btu/hr ft}^2$$

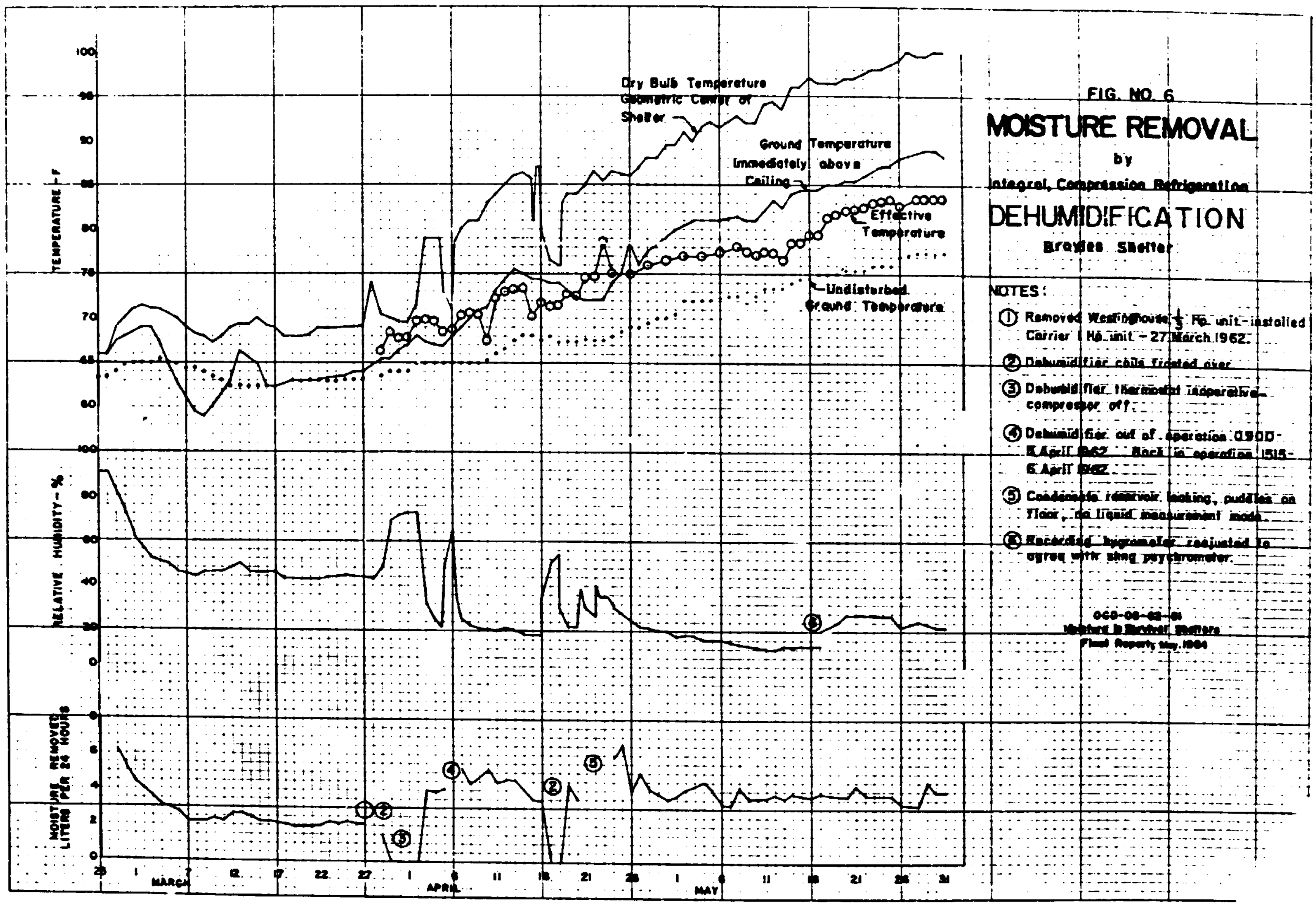
FIG. NO. 6
MOISTURE REMOVAL
by
Integral Compression Refrigeration
DEHUMIDIFICATION
Brayles Shelter
NOTES:
① Removed Westinghouse ½ Hp. unit - installed Carrier 1 Hp. unit - 27 March 1962.
② Dehumidifier coils frosted over.
③ Dehumidifier thermostat inoperative - compressor off.
④ Dehumidifier out of operation 0900 - 5 April 1962. Back in operation 1515 - 6 April 1962.
⑤ Condensate reservoir leaking, puddles on floor, no liquid measurement made.
⑥ Recording hygrometer readjusted to agree with sling psychrometer.
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Dry Bulb Temperature Geometric Center of Shelter
Ground Temperature Immediately above Ceiling
Effective Temperature
Undisturbed Ground Temperature
TEMPERATURE - F
RELATIVE HUMIDITY - %
MOISTURE REMOVED LITERS PER 24 HOURS
MARCH
APRIL
MAY

On March 29, the 1/3 horsepower Westinghouse dehumidifier was replaced by a one horsepower Carrier unit. During the period from March 27 to March 29, no dehumidification was being effected, and it appeared that the driving force for moisture migration was great enough so that the relative humidity within the shelter rose. The additional rise in relative humidity during the period from March 29 to April 2 was due to the fact that although the larger dehumidifier was operating, its function switch had been turned to maximum cooling - manual control, and as a result the dehumidification coil became coated with frost, and air was not able to pass through the coil. When the unit was placed on thermostatic control, the frost melted, and an immediate reduction in relative humidity was noted. During the remaining period of the test, minor malfunctions of this unit occurred (principally freeze-ups) but the general trend of humidity and moisture removal stabilized at 15 % relative humidity and 3.7 liters of water per day. This indicated that equilibrium had been established between the dry interior and the wet earth surrounding the shelter, and that the moisture removal rate represented the transfer of vapor through the waterproofing materials.

Finally, it should be noted that during this period of the test, there was a gradual but regular rise in dry bulb temperature. The actual power consumption was 8.5 amps at 115 volts so that for this latter period, heat was being released at the rate of:

$$(8.5)(115)(3.413)(24) + \frac{(3.7)(1000)(1055)}{(454)} = 80{,}070 + 8{,}600 = 88{,}670 \text{ Btu/day}$$

In terms of equivalent occupants, the total heat release (motor power plus heat of condensation) is:

$$\text{Thermal Equiv. Occupants} = \frac{88{,}670 \text{ Btu/day}}{\frac{400 \text{ Btu}}{\text{Hour, Occupant}} \times 24} = 9.24$$

The vapor infiltration, as measured by the dehumidifier water output is equivalent to:

$$\text{Moisture Equiv. Occupants} = \frac{3.7 \text{ liters/day}}{\frac{0.1024 \text{ liters}}{\text{Hour, Occupant}} \times 24} = 1.51$$

During this phase of the dehumidification experiment, the heat transfer rate rose to 88,670/(600)(24) or 6.15 Btu/hr ft^2. In order for this quantity of heat to be transferred, an increased driving force became necessary as evidenced by the rise in shelter temperature. The ground temperature outside the shelter walls was also being affected as indicated by the curve of Figure 6.

A question might arise as to whether the water being removed, originated within the shelter walls, in the earth surrounding the shelter, or indeed in the atmosphere outside. These questions

can probably be resolved by reference to Figure 6 and Figure 7. The latter is a reproduction of a chart from a recording temperature and humidity sensing device and covers the period when the large dehumidifier had just been substituted for the 1/3 horsepower unit. From Figure 6, it may be inferred that the shelter walls were being dried out during the period from February 27 to March 8. After this the water removal reached a steady value, indicating that it was originating in a large source. If this water originated in the walls themselves, it appears that a further and continuing diminuition of rate would have occurred during the nearly two months that the test was in progress.

Study of Figure 6 indicates that subsequent to its installation on March 27, the large dehumidifier did not begin to function properly until April 2. As explained earlier, the dehumidification coil was frosting up. On April 2, a successful adjustment was made and the unit began removing water. Figure 7 indicates that the unit was operating in a cyclic fashion. Examination of the equipment during this period revealed that the coils were still frosting, but that the control unit was sensing this frost and turning off the compressor while allowing the fan to continue operation, thereby melting the accumulated ice. Each time this cycle occurred, there was a cooling of the shelter air and a sharp increase in relative humidity. This latter effect has two causes, the humidifying effect of the dehumidifier fan blowing the previously dried air over the frost laden coils, and the moisture contribution being made continuously to the shelter environment by moisture migration through the walls, or by infiltration through the entrance way seals. This latter possibility can be largely ruled out by further study of Figure 7. Taking the period from April 3 to April 4 as being fairly representative of the operation of the large dehumidifier, the conditions within the shelter can be compared to the external conditions, determined from the Weather Bureau data. During this time, weather conditions fluctuated from 34 F - 100% relative humidity at 0700 to 65 F - 21% relative humidity at 1400. When values of temperature and relative humidity for the whole period were considered an average value of specific humidity of twenty-four grains, water per pound of dry air was obtained. From Figure 7, an average value of temperature of 79 F and of 25% relative humidity may be estimated indicating that an average value of specific humidity of thirty-seven grains was being maintained within the shelter. Thus, any air that infiltrated the shelter was actually drier than that which was already present inside, so it could not contribute to the moisture load being removed by the dehumidifier. Values of ambient temperature and relative humidity for the Gainesville, Florida area are shown in Figure 8.

In conclusion, it should be pointed out that the final equilibrium conditions reached within the shelter, of 45% relative humidity with the 1/3 horsepower unit, and of 22% humidity with the one horsepower unit, represent drier conditions than might be expected during actual occupancy of the shelter. Therefore, the driving force causing vapor transfer through the walls was greater than

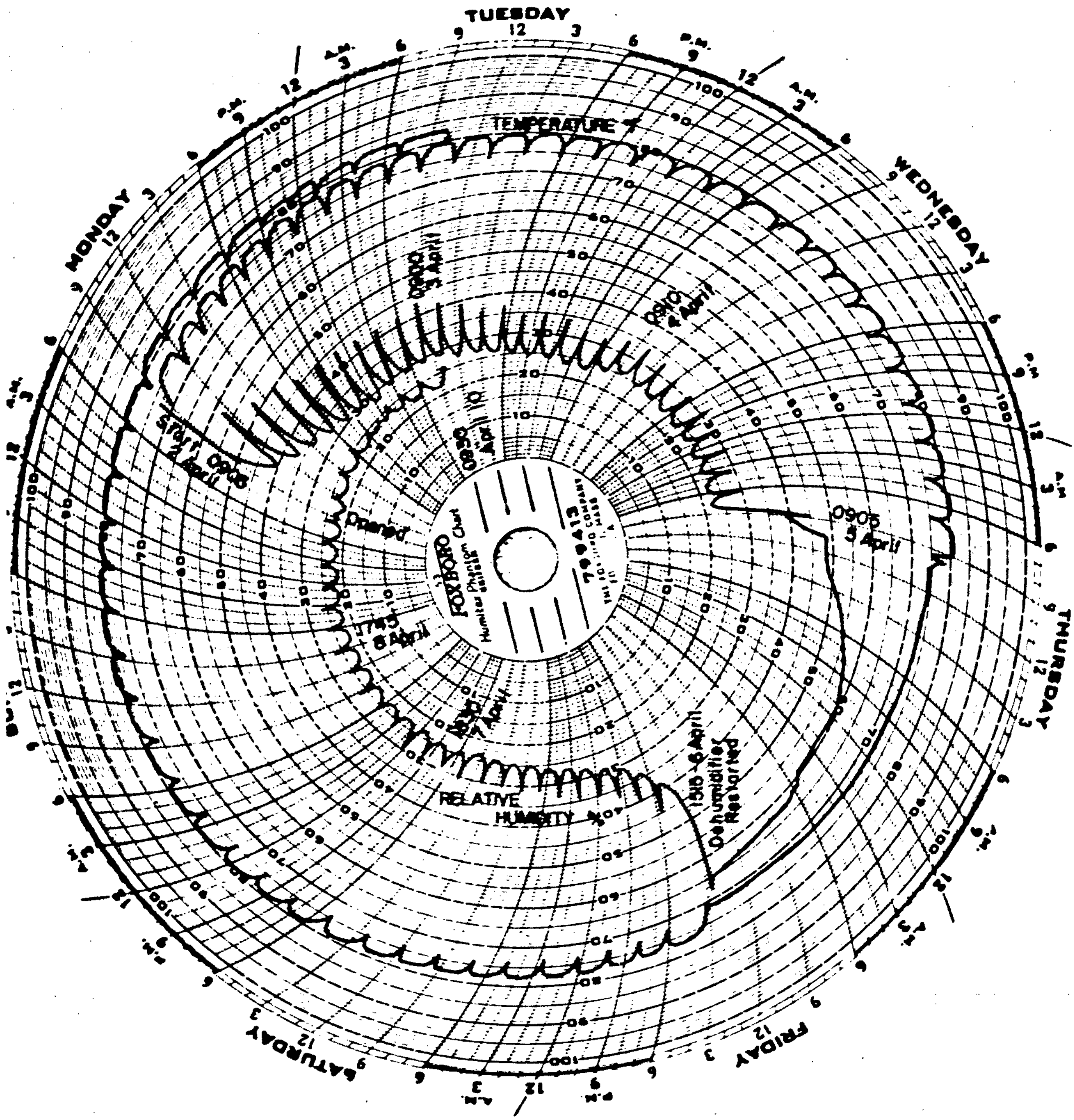

Fig.7 – Temperature and Humidity Variations During Dehumidification – Typical Chart Broyles Shelter – 2 April–10 April 1962

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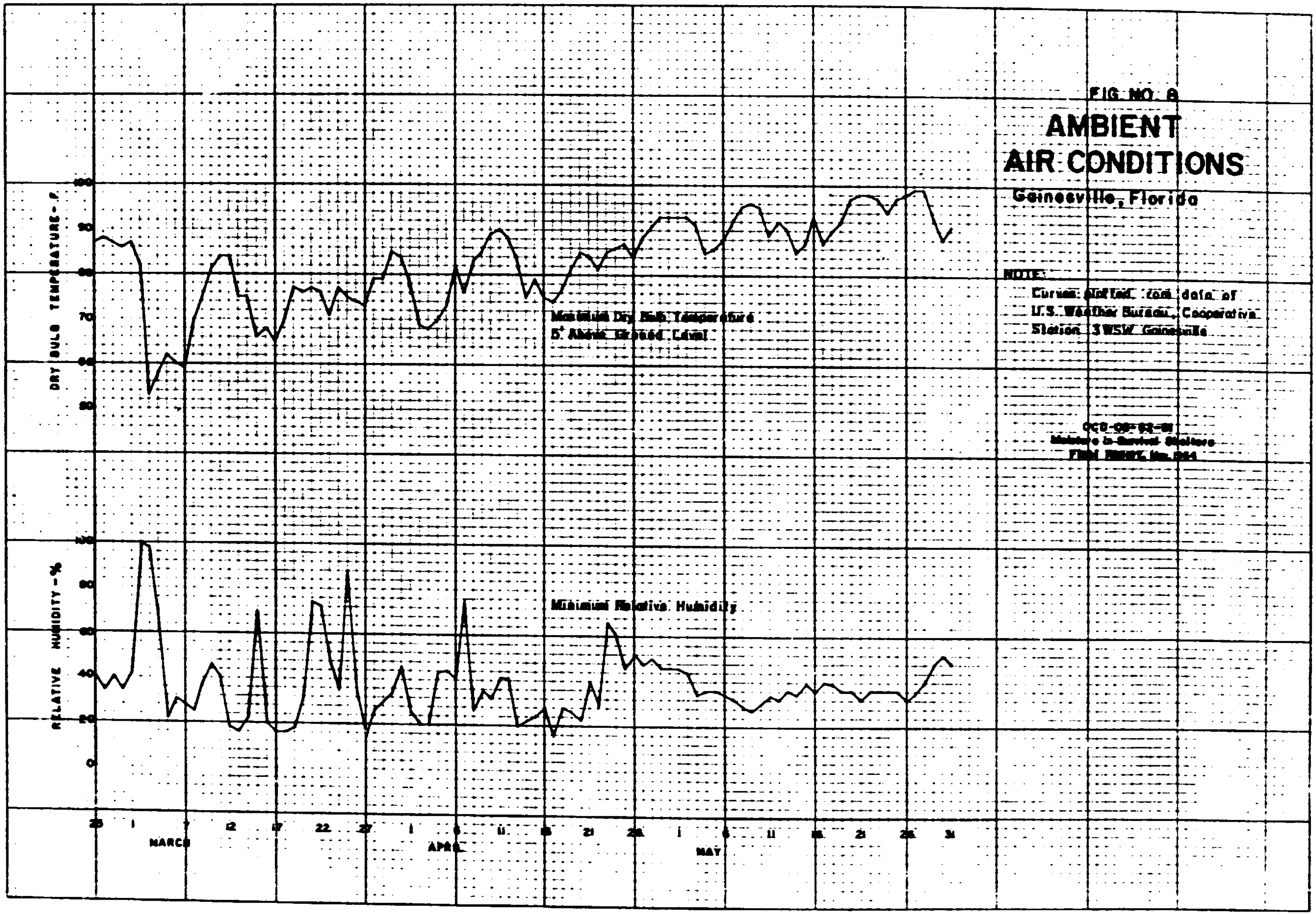

FIG. NO. 8
AMBIENT AIR CONDITIONS
Gainesville, Florida

normal. However, it may be significant to note that during the period from March 29 to April 2, when the dehumidifier was not functioning properly, the relative humidity rose sharply and indeed was still rising after it had reached a value of 70%. This would indicate that the equilibrium relative humidity for this shelter was greater than this amount and may even have approached the 90% value at which the test started. Thus, vapor migration would still contribute to the moisture loading of this shelter at any value of inside relative humidity in the range of 70 to 90%.

A similar test was performed in a buried tank type shelter with the results summarized in Figure 9. Only the 1/3 horsepower Westinghouse unit was used. It can be seen that an equilibrium condition was reached, in this case at a value of relative humidity of 32 to 34%. It seems probable that the rate of water removal of about 0.2 to 0.3 liters per day represented the "breathing" of the shelter with minor changes in atmospheric pressure rather than a leak of moisture through the walls.

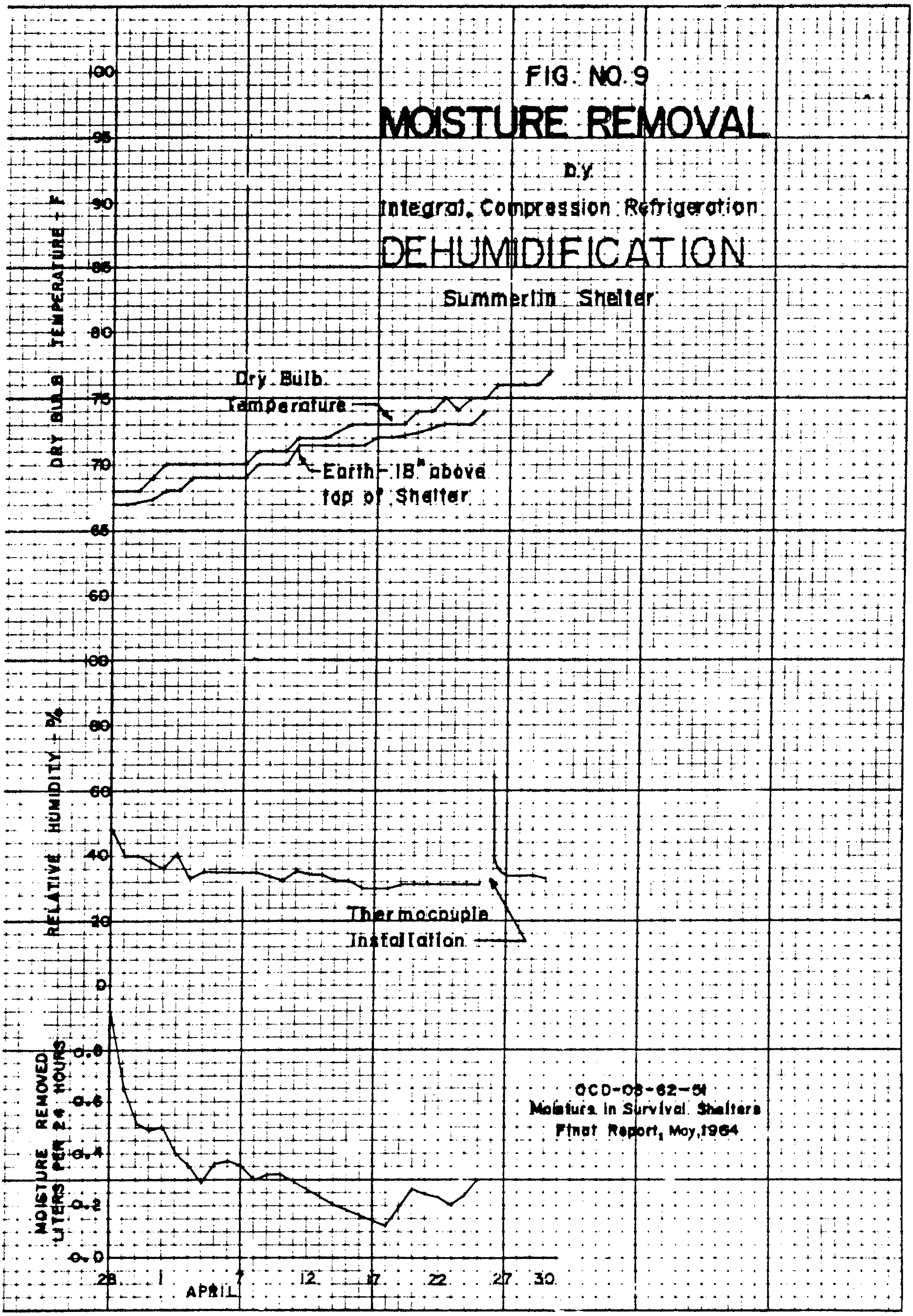
FIG. NO. 9
MOISTURE REMOVAL
by
Integral, Compression Refrigeration
DEHUMIDIFICATION
Summerlin Shelter
DRY BULB TEMPERATURE - F
RELATIVE HUMIDITY - %
MOISTURE REMOVED LITERS PER 24 HOURS
Dry Bulb Temperature
Earth - 18" above top of Shelter
Thermocouple Installation
APRIL
OCD-OS-62-51
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Air Infiltration Tests. During the course of the investigation, questions arose concerning the ability of the entranceway hatches to seal shelters against air infiltration. This became particularly important during periods when tests were under way to study vapor migration through walls, since a substantial infiltration of moisture laden air would have invalidated these tests. In order to isolate the effect of the hatchway seals, all other openings were sealed with a plastic film and carefully taped. The shelter being tested was then entered, and approximately fifteen pounds of solid CO_2 ("dry ice' was placed on the floor and broken into small pieces. The shelte was closed and by means of a sampling tube the concentration of CO_2 within the shelter atmosphere was measured using an Orsat typ flue gas analyser. The concentration of CO_2 was plotted against time on semi-log paper as shown in Figures 10 and 11. From these curves, a value of 0.2 air changes per hour was obtained for the concrete block shelter, while for the steel tank shelter, the rat was determined to be 0.008 changes per hour.

The rate for the concrete block shelter seems high, when it is compared with other rates from the literature for concrete block houses.* It has since been pointed out that CO_2 is a particularly unfortunate choice of gas to use for an infiltration test based on declining concentration measurements, since it may be expected to react with and also be absorbed into cementitious materials even though these materials were quite dry. Without doubt, these phenomena occurred in the test reported on in Figure 10 and thus contributed to the high value of infiltration. However, the results of this test are not completely invalid, since the test depicted was the second of two conducted on the same shelter in a period of only seventy-two hours. Thus, some saturation of the surface with CO_2 may be assumed to have taken place. In the case of the test on the steel tank type shelter, the use of CO_2 as a test gas was entirely satisfactory, since only minor absorption may be assumed to have taken place.

* Glover, C. W., Civil Defense, Chemical Publishing Co., Brooklyn, N. Y., 1941, pg. 105-120

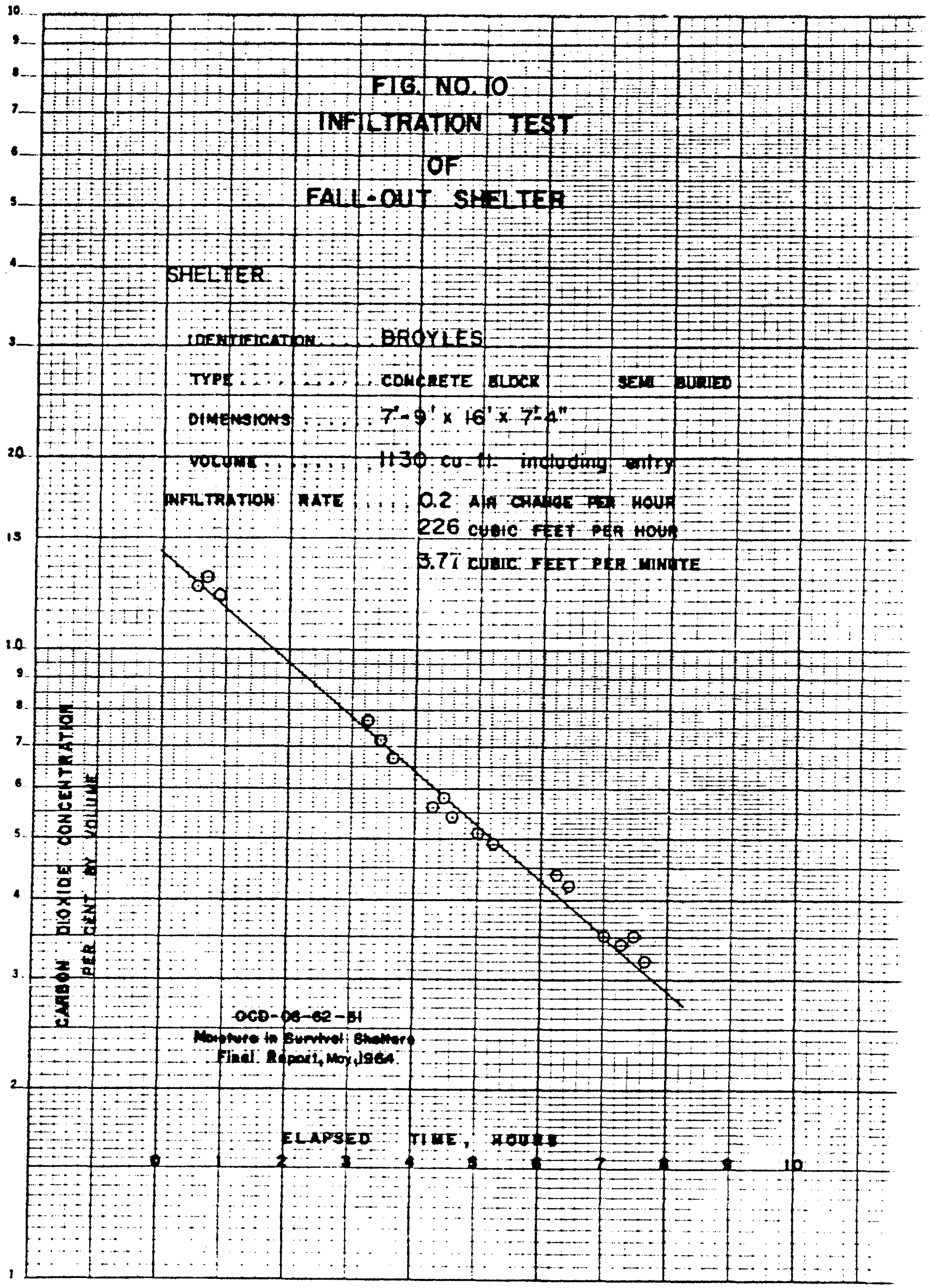
FIG. NO. 10
INFILTRATION TEST
OF
FALL-OUT SHELTER
SHELTER
IDENTIFICATION .... BROYLES
TYPE .... CONCRETE BLOCK SEMI BURIED
DIMENSIONS ..... 7'-9' x 16' x 7'-4"
VOLUME .... 1130 cu. ft. including entry
INFILTRATION RATE .... 0.2 AIR CHANGE PER HOUR
226 CUBIC FEET PER HOUR
3.77 CUBIC FEET PER MINUTE
CARBON DIOXIDE CONCENTRATION
PER CENT BY VOLUME
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ELAPSED TIME, HOURS
0
1
2
3
4
5
6
7
8
9
10
1
2
3
4
5
6
7
8
9
1.0
15
20
3
4
5
6
7
8
9
10

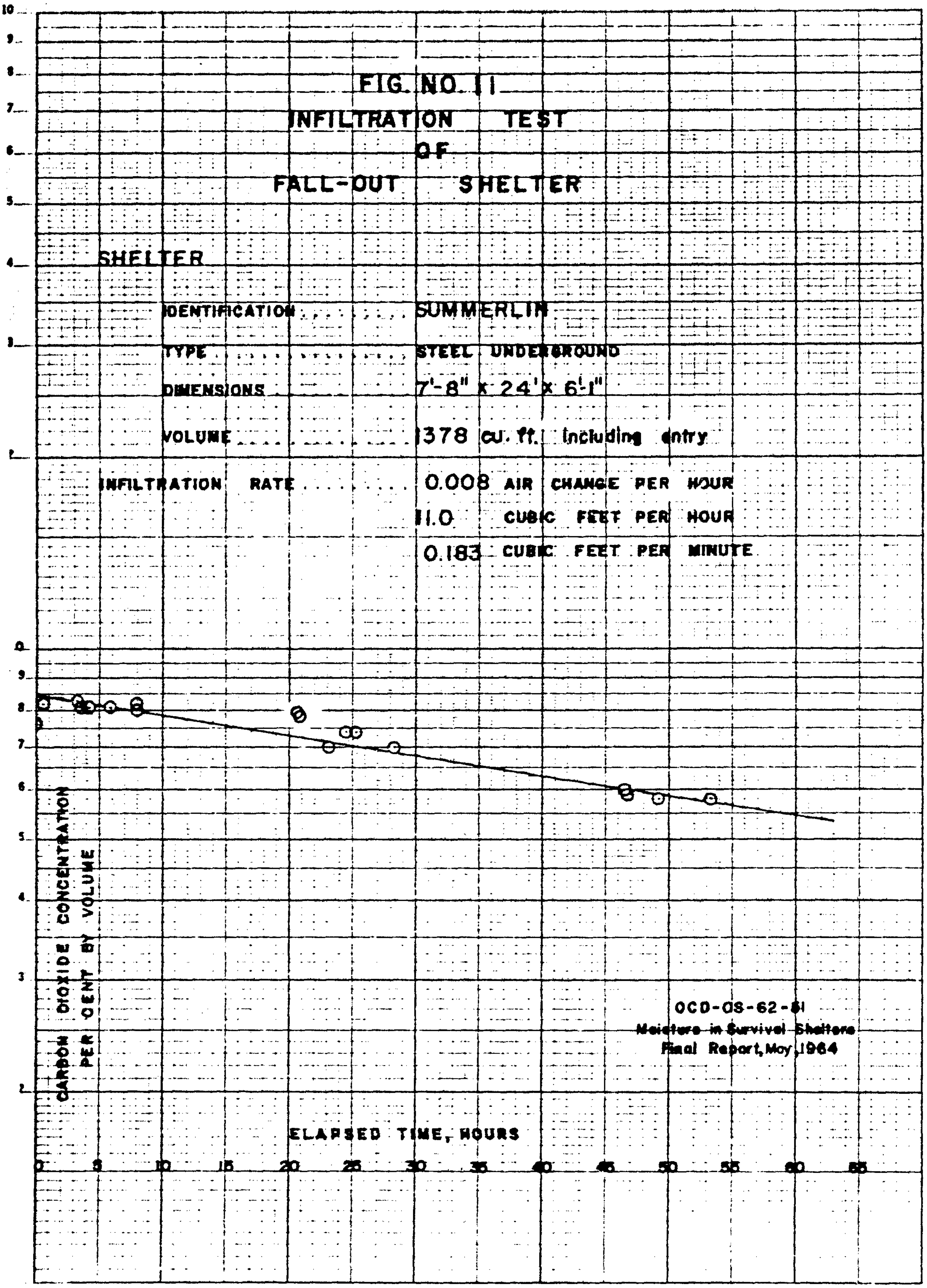


FIG. NO. 11
INFILTRATION TEST
OF
FALL-OUT SHELTER
SHELTER
IDENTIFICATION .... SUMMERLIN
TYPE .... STEEL UNDERGROUND
DIMENSIONS .... 7'-8" x 24' x 6'-1"
VOLUME .... 1378 cu. ft. including entry
INFILTRATION RATE .... 0.008 AIR CHANGE PER HOUR
11.0 CUBIC FEET PER HOUR
0.183 CUBIC FEET PER MINUTE
CARBON DIOXIDE CONCENTRATION
PER CENT BY VOLUME
ELAPSED TIME, HOURS
0 5 10 15 20 25 30 35 40 45 50 55 60 65
OCD-OS-62-81
Moisture in Survival Shelters
Final Report, May, 1964

Metabolic Moisture and Heat. In shelters the primary internal thermal load comes from the occupants. Extensive research conducted over a period of thirty years by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE Guide and Data Book - 1961) has established the heat loads which human beings generate. These loads are referred to as the metabolic heat release of human beings, and they vary with respect to the activity of the human being. In general, for human beings at rest or performing sedentary tasks, the rate has been found to be 400 Btu per hour. This heat release rate is broken down into two parts: sensible heat release and latent heat release. The amount of each is dependent upon the ambient dry bulb temperature; thus, at 80 F it is generally accepted that the sensible heat release is 200 Btu per hour and the latent heat release is 200 Btu per hour for persons at rest. As the dry bulb temperature increases, the sensible heat release drops and the latent heat release increases. At 100 F, the latent heat release constitutes 100% of the total heat released by a human being. Other tests in the field of medical research, (Medical Physiology and Biophysics), Ruch and Fulton, edition 18, pages 981-982), verify these values. Tests such as those performed by the Bureau of Yards and Docks under Task YFO 11-05-331 also support these values.

These values for metabolic heat losses are not beyond scrutiny for use in shelters. The results of various investigators are somewhat divergent, particularly with respect to the partitioning into sensible and latent fractions. Also, metabolic heat losses are usually determined for "young adult males" and in this respect may not represent a typical shelter loading which might be expected to comprise a cross section of the overall population. Further, the stress under which all the occupants might be expected to be placed might well tend to alter metabolic rates. Again, due to the limited space available in shelters, good management would dictate that from 1/3 to 1/2 of the persons present might be expected to be reclining or asleep at any one time, and hence contributing heat at a lower rate than those eating, reading, or engaged in other sedentary tasks. For these reasons, 400 Btu per hour was selected as being representative of the metabolic rate to be expected.

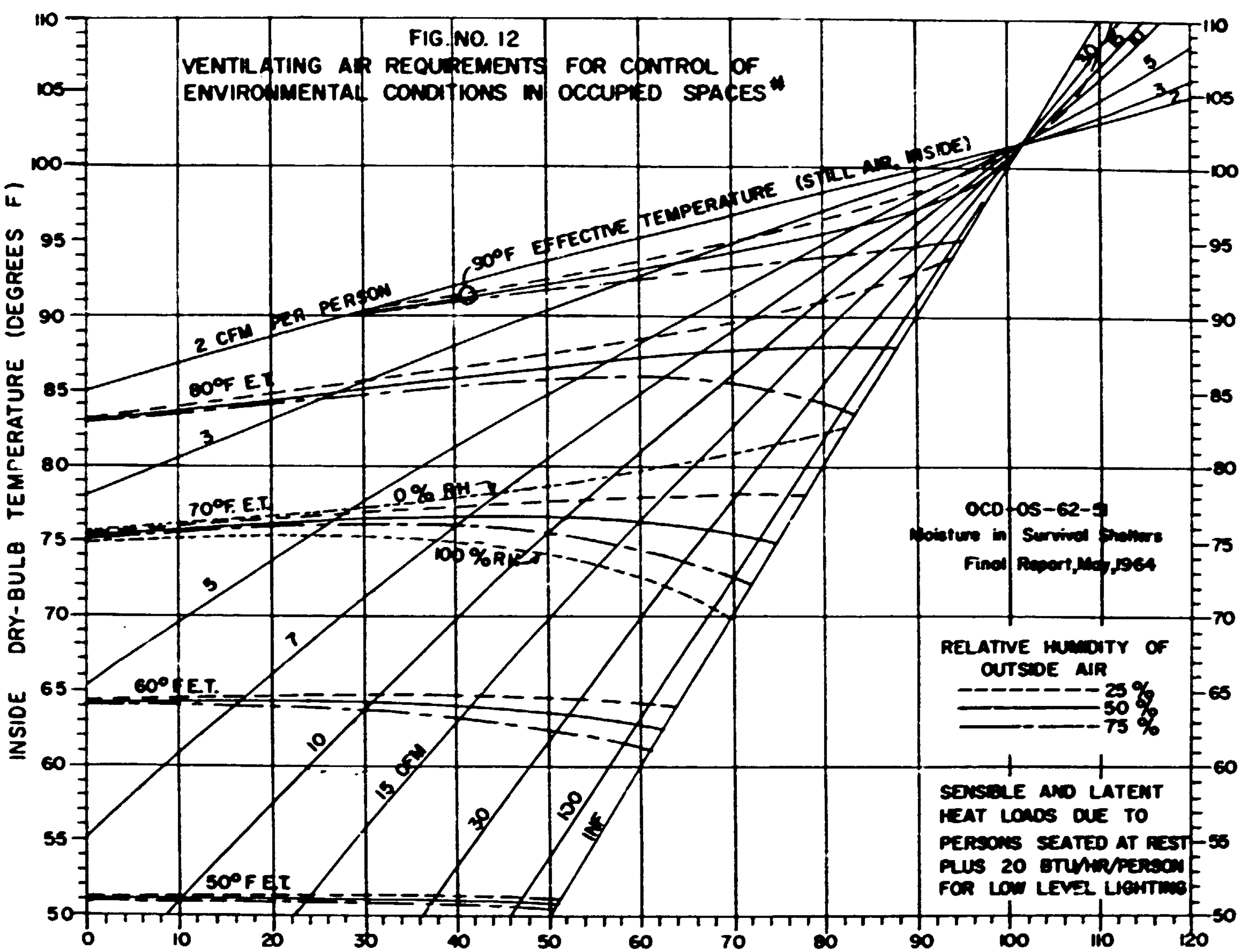
Ventilation Air. Moisture in the ventilation air varies with respect to geographic location and constitutes a greater problem with respect to shelter environment in hot humid climates. If the absolute humidity of the ventilating air is high, the amount of moisture that such air can remove from the shelter is limited. While the amount of moisture in pounds or grains which is brought into the shelter by the air required to meet the oxygen requirements of the occupants is small, it should be recognized that the moisture content of the ventilation air will affect the amount of such air required when it is used as a means of controlling environmental conditions within the shelter.

"The curves in Figure 12, can be used to estimate the ventilating air requirements for control of environmental conditions in occupied spaces.* On this chart various per capita rates of ventilation are plotted as a function of outside and inside dry-bulb temperatures and upon this background are superimposed the 50, 60, 70, 80, and 90° F still-air inside effective temperature curves for outside relative humidities of 25, 50, and 75 percent. The 70° F inside effective temperature curves for outside relative humidities of 0 and 100 percent are also shown. The heat and moisture loads upon which this chart is based consist of the sensible and latent heat emitted by a man seated at rest plus 20 Btu/hr/person for low level lighting, that is, about 6 watts per person. Other heat loads and the transient cooling effect of earth conduction are not considered.

The chart may be used to estimate the supply air quantity, temperature and relative humidity necessary to maintain a given effective temperature in a shelter. For instance, an effective temperature of 80° F can be maintained in a shelter with 15 cfm of air per person distributed at a dry-bulb temperature of 78 F and 50 percent relative humidity. The dry-bulb temperature in the shelter would be 88 F.

*From Ventilation Requirements and Design, by F. C. Allen of the Research Directorate, Office of Civil Defense, in a paper delivered to a pilot course to develop an Instructor's Manual of Environmental Engineering for Fallout Shelters. The course was conducted at the University of Florida in the summer of 1963.

FIG. NO. 12
VENTILATING AIR REQUIREMENTS FOR CONTROL OF ENVIRONMENTAL CONDITIONS IN OCCUPIED SPACES*



* From Mechanical Equipment Requirements in Survival Shelters by Frank C. Allen.

III. INTEGRAL DEHUMIDIFICATION METHODS AND DEVICES

Thermodynamics of Dehumidification. If a device to remove moisture from air is to be totally contained within the space in which it is to operate, it may be analyzed by the so called "black box" technique of thermodynamics. In this method of analysis, the details of construction and operation of the device in question are ignored and only the overall effects and energy flows are considered. Using this technique and referring to Figure 13, let the first consideration be the static or non-flow system illustrated there.

In its initial state, Condition 1, a shelter enclosure is typified by the external box. Enclosed within this shelter are V_1 cubic feet of air with an initial condition of temperature T_1, pressure P_1, moisture content (as vapor) W_1 pounds and enthalpy or total heat content of air and associated moisture, H_1 Btu. The typical numerical values shown are for a shelter space filled with hot, humid air. By restricting the problem under consideration to one pound of dry air together with its associated moisture, the values shown become the so called "specific" values, or those pertaining to a basic unit of measure, in this case, that of one pound of dry air. For example, the total volume of the shelter, V_1 cubic feet now becomes $V_1 = 14.4$ cubic feet of mixed gases (air and water vapor) per pound of dry air.

The "black box" is shown and is assumed to contain some type of a dehumidifying device (refrigeration engine, desiccant material, absorbent, or other means of moisture removal). Probably the only restriction that need be put on the box and its contents is that it not have within itself the ability to store energy.

Now it is assumed that the "black box" has been allowed to act for whatever time is necessary to perform its function which is that of reducing the humidity within the shelter from its initial value of 70% to some lower value. Conditions in the shelter are now those shown as Condition 2. It is assumed that it is appropriate to determine the final conditions of temperature, pressure, enthalpy, etc., for the shelter when a value of 50% relative humidity has been obtained, and also to ascertain whether these conditions are more conducive to comfort than those originally existing.

Referring to the skeleton psychrometric chart of Figure 13, the initial condition of the air is plotted as Point 1, and all that is known of Point 2 is that it must lie on the 50% relative humidity line. Applying the "First Law of Thermodynamics", which is a statement of the conservation of mass-energy, to this system, it can be concluded that if no energy enters or leaves the system

THERMODYNAMICS OF INTEGRAL DEHUMIDIFICATION DEVICES

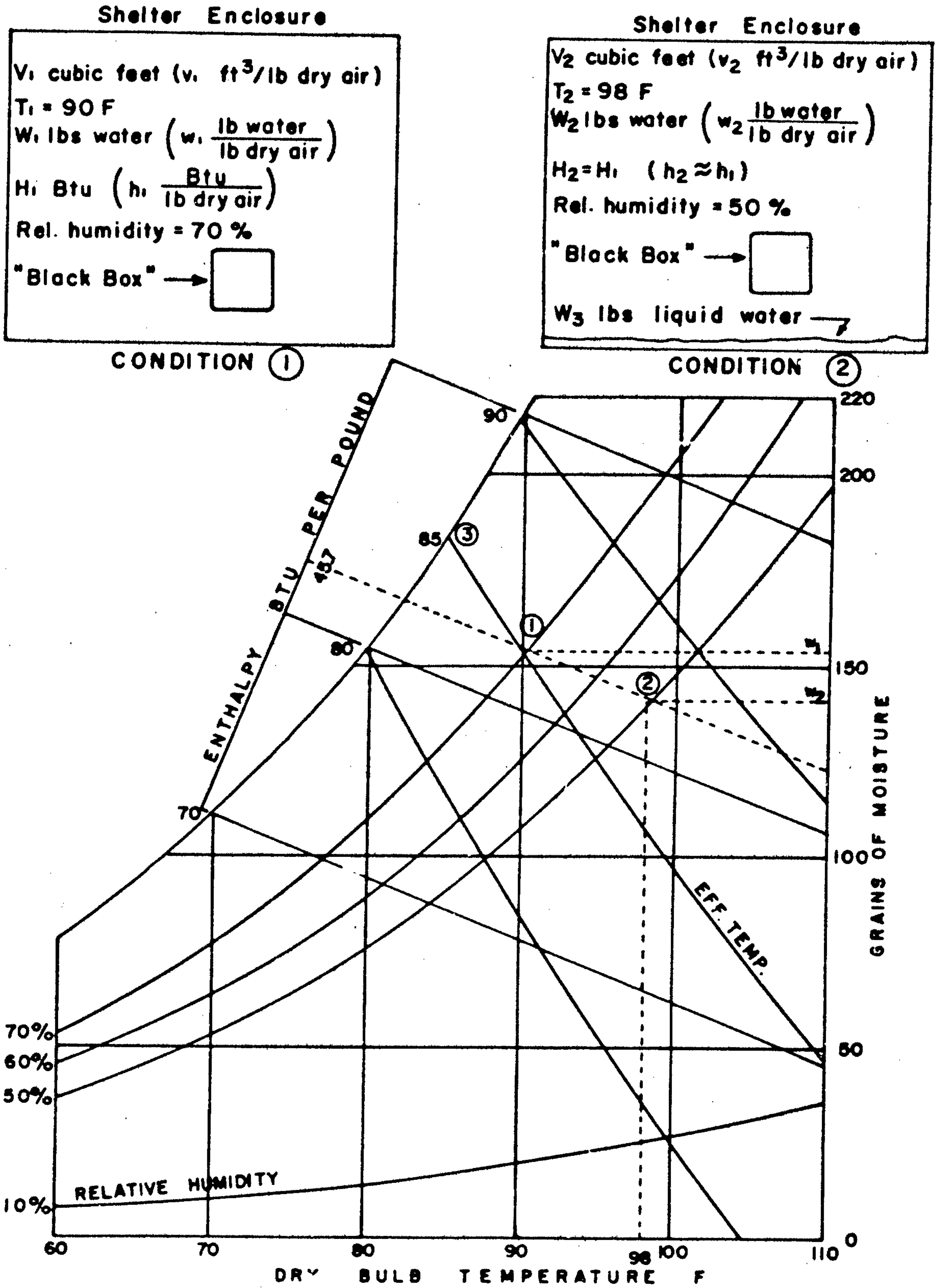


FIG. NO. 13

ich comprises the air within the shelter and its associated ter vapor, then the process can be considered one of constant thalpy, and be so indicated on the psychrometric chart. By llowing the line of constant enthalpy of 45.7 Btu/lb through e initial Point 1, until it intersects the desired final contion of 50% relative humidity, a final condition of 98 F is ached. Thus, the air has been heated as it was being dried, d this was found to be true without making any specification to the mechanism of the process except that it be carried t without energy transfer to or from its surroundings.

Lines for 80 F, 85 F, and 90 F, effective temperature have en plotted, and it can be seen that these lines are not parallel the constant enthalpy line previously mentioned. Further examition will reveal that if a drying operation was conducted at a nstant enthalpy, it must of necessity have reached a final point higher effective temperature. This follows from the fact that e drying of air results in a lower relative humidity as well as wered specific or absolute humidity, i.e., a process proceeding om upper left to lower right on the chart. The term effective mperature and its significance is of vital importance in air nditioning theory and practice. The effective temperature is measure of the physiological effects of the combination of mperature, relative humidity, and air movement. For the region interest to this investigation, the effective temperature may y be approximated as:

$$E.\ T. = 0.4\ (\text{Dry Bulb Temp., } {}^{o}F + \text{Wet Bulb Temp., } {}^{o}F) + 15$$

As can be seen from the skeletonized psychrometric chart, air ich is saturated (and which has a flow velocity of twenty feet r minute or less) has an effective temperature equal to its wet lb temperature (Point 3). Following the line of constant effecve temperature of 85 F, it will be noted that other combinations drier and warmer air have this same value, so that it can be ated that air at a temperature of 112 F and with a relative midity of 10% still has an effective temperature of 85 F. Such combination might exist for climatic conditions in a desert cation. The value of effective temperature of 85 F has been lected as an example, since a study of available literature indites (Temperature and Human Life, Princeton University Press, 1949; E. A. Winslow and L. P. Herrington, ASHVE Transactions, Vol. 30, 24.) that human beings cannot continue to function normally for tended periods at or above these conditions.

Therefore, anything that raises the effective temperature t least in the range of 72 F and above) may be considered to ve a deleterious effect on the habitability of a protective elter. Unfortunately, any drying process which may be assumed take place without energy interchange with the surroundings, st result in this undesirable eventuality. In an actual shelter, e first assumption made i.e., that the "black box" dehumidifier quired no energy input, is not correct, since some energy must

be put into any dehumidification device to make it work. The moisture that is in the air will not spontaneously be condensed to a liquid phase. The energy sources might be electrical energy to power a compression refrigeration machine, or the utilization of the stored chemical energy, or surface energies of absorbents (calcium chloride), or adsorbents (silica gel, activated carbon, etc.). In any event, these energies either enter such an imaginary system or exist within it in a form which has not been accounted for in the initial tabulation of the properties (particularly the enthalpy) of the original moist air. In causing the dehumidifier to "work" these originally unaccounted for energies become part of the system, and, since it was presupposed that the "black box" device could not store energy in the final condition, thus make a contribution to the final enthalpy of the system. Therefore, these drying processes are really constrained to be ones of increasing enthalpy with their concomitant additional increase in effective temperature.

It may be concluded that when air is dried with a device which is physically completely located within the space being dehumidified, that the air is heated in the process, and the resulting temperature rise is such that the effective temperature is increased with a resulting loss in habitability.

Even though a theoretical analysis, as previously described, indicated that a self-contained dehumidification process would not work as a means of controlling environment in survival shelters, a series of tests were conducted in order that experimental data be available to support the results indicated by a theoretical study. In retrospect, it may be difficult to justify such experimentation. However, the authors were of the opinion that many people who might at some time review this report would be so firm in their convictions that a direct relationship existed between humidity and comfort that experimental results would go far to remove doubts which might exist with respect to the preceeding theoretical analysis which deals with a special case where the humidity within a space may be lowered without provisions being made for removing the sensible heat released by the condensing moisture. The expression, "It's not the heat but the humidity," has become so common and apparently gained such a degree of validity simply by the process of being repeated, that there was a definite feeling that more than a paper study would be necessary to convince the average person that a reduction in humidity under certain circumstances would not per se bring about a better and more comfortable environment. In fact, the authors are of the definite belief that doubts would have existed in their own minds in the absence of experimental data which did in fact support the predicted results of the paper study.

The use of self-contained dehumidification processes during the winter months could be a means of controlling condensation within a survival shelter and could supply sensible heat that might be needed in climates where the ambient winter temperature

was below 50 F.

The research involving the use of integral dehumidification equipment followed three approaches: the use of electrically driven compression refrigeration devices; an attempt to devise a type of wallboard with a high water storage capability; and finally, the use of chemical agents which would absorb moisture from air directly. Moderate success was attained in all these efforts and only detailed examination of the data from two actual full scale applications revealed that while water was being removed, the overall effect was to increase the effective temperature for the reasons just outlined.

Mechanical Dehumidification. The use of a mechanical refrigeration device with both condenser and evaporator contained in the same space is not new. Such "driers" or "dehumidifiers" have been on the market for several years. Reference to the advertising literature will show that the principal advantage cited for such devices is the improvement in the long term storage capability of the space dehumidified. Rust is readily prevented by low humidities, and since the growth of molds is also inhibited, some improvements in the odor of storage areas may be expected. Any claim that such devices make a space more "liveable" would be open to serious question.

Two devices of this nature were used in a radiation shelter of concrete block type construction. The dehumidifiers used operated on a refrigeration principle, namely they contained a compressor, an evaporator and a condenser in a single package. Shelter air was forced across the evaporator where dehumidification and cooling took place. The cool air was then passed across the condenser where it was reheated. Primarily, the purpose of this experiment was to determine the rate at which moisture was diffusing through the walls, but data on the temperature-humidity history of the shelter were also taken. The results of the test are discussed and summarized in an earlier section entitled, "Vapor Migration Through Walls", and in Figure 6, which accompanies that section. The experiment may, however, be considered as an attempt at dehumidification. The reader's attention is directed specifically to the curves of Relative Humidity, Shelter Dry Bulb Temperature, and Effective Temperature, as shown in Figure 6.

First, it may be noted that the shelter reached two stable relative humidity levels, dependent on whether a 1/3 horsepower dehumidifier was used, or one of a one horsepower rating. This stabilization indicates that the dehumidifier had lowered the shelter humidity as far as possible, considering the constant influx of water vapor through the walls, and the refrigeration capacity of the particular machine. The load on the dehumidifier, while here provided by vapor migration through the walls, would, during occupancy, be the moisture in the exhalations of the occupants. Doubtless the equilibrium relative humidity would then be higher, but there seems no doubt that some sort of equilibrium would be reached in time.

Second, it may be seen from the curve of the effective temperature, (which is plotted only for the period when the one horsepower unit was operating), that this line has a continuous upward trend, broken only at two points. These dips in the curve occur during the periods April 5 - 6, and April 14 - 19. In each case, a note on Figure 6 indicates a shut down or malfunction of the dehumidifier. As can be seen, the relative humidity rose sharply on these occasions, while the dry bulb temperature decreased. This latter effect can be attributed to the fact that

while the entire shelter was still conducting heat away to the colder earth environment, the production of heat by the electrical input to the dehumidifier and the production of heat, by the condensation of water vapor had both ceased. Thus, although the humidity rose, its effect in determining effective temperature was more than off-set by the drop in temperature.

Not so however, during periods of stable operation. Taking the period May 17-31, as an example, the relative humidity remained fairly constant at 22% to 26%. During this same period the dry bulb temperature rose from 96 F to 100 F and the effective temperature rose from 79 F to 83.5 F. While this rise would not be deleterious to materials stored within the shelter, it would have been most noticeable to shelter occupants and indeed by May 31, the shelter environment with its effective temperature of 83.5 F was approaching the danger point of 85 F, above which human beings cannot long exist without physiological damage.

It is concluded therefore, that humidity control by integrally contained compression refrigeration type dehumidification equipment is not practical for radiation shelters during periods of occupancy.

The net effect of using any device of this type is to increase the total energy level within the shelter. The increase in energy level is equal to the work input to the compressor and results in an increase in dry bulb temperature. The dehumidification process results in a lowering of the absolute and relative humidity of the air within the shelter, but all of the latent heat transferred during the dehumidification process appears as sensible heat in the shelter air and results in a further increase in the dry bulb temperature. Thus, the net effect on the effective temperature within the shelter is an increase in temperature which would make the shelter unsuitable for human occupants if this condition was continued for a period of time. However, mechanical dehumidifiers would be useful as a means of drying out masonry shelters immediately after construction. They would be useful as a means of keeping shelters in a proper condition on a standby basis if they were used in conjunction with blowers which would remove the sensible heat released by the compressor and the latent heat produced by the condensation of moisture from the shelter air.

In cases where mechanical dehumidifiers are used as a means of maintaining acceptable humidity levels in shelters during periods when the shelters are not in operation, difficulties can be encountered due to frost forming on the evaporative coil when ambient temperatures are below 65 F. For this reason some means of sensing low evaporative temperature or pressure should be a part of such dehumidifiers and such devices could be coupled to control switches in such a manner as to shut the unit off for a predetermined period which would permit the frost to melt or else reverse the refrigeration cycle so that hot gas would enter the evaporator and cause the

frost which had formed to melt. The use of such a device during periods when the shelter was not occupied may be advisable since low absolute and relative humidities would tend to protect furnishings, clothing, and can goods from deterioration related to high moisture content. Reference to Figure 6 will show an instance where a mechanical dehumidifier, equipped with a frost sensor, was cycling on and off due to frost buildup, but on an overall basis, was doing an acceptable job of dehumidification.

Absorption Dehumidification (In untreated and treated cellulosic materials). The second approach to the problem of dehumidification by devices wholly contained within the shelter itself involved an attempt to utilize the absorptive properties, first of cellulosic materials, next of chemically treated cellulose, and finally of pure desiccant chemicals. From experience with wood pulp as manufactured for the paper industry, it was known that "boards" or sheets of this material develop some slight mechanical strength at values of water content of 75% or less, depending somewhat on fiber type and length. It was considered that this material might be suitable in a dried form as a liner for radiation shelters. The board would be as nearly free from moisture as possible and protected before use by some sort of impermeable membrane. The latter would be stripped away when it became necessary to occupy the shelter, the previously dried wood pulp then taking up moisture until its water content came to some equilibrium with the environmental atmospheric moisture.

Tests were conducted using sheets of wood pulp of various types and it was found that while these materials would indeed "hold" up to 75% water after immersion in liquid water, their equilibrium moisture content averaged only 20% when they were exposed for periods of several days in an atmosphere kept at 80% relative humidity. With an apparent density of about forty pounds per cubic foot, a liner of this material would weigh about 3.3 pounds per square foot per inch of thickness. If a nominal fifty square feet of area be assigned to each person (this includes wall, ceiling and floor area) then each person might readily have 165 pounds of absorbent fiber available to absorb his metabolized moisture. On the basis of an increase in moisture from 0% to 20% (based on dry weight), this amount of fiber would pick up thirty-three pounds of water, or about four gallons. Since the average person may be expected to evaporate about five pints per day, this absorptive capacity would be sufficient for about six days of occupancy.

In order to assure sufficient absorptive capacity for the expected period of fourteen days, the occupant of a shelter (in which the pro-rata share of the wall, ceiling and floor area was fifty square feet) would need to have this area covered with a thickness of about 2 1/3 to 2 1/2 inches of initially bone dry fiber board. This seemed an unreasonable amount of absorptive material, so this particular approach was modified.

It was felt that if the pure fiber, which would reach an equilibrium moisture content of 20%, were combined with a chemical with a high affinity for moisture, it might be improved or "promoted." To this end, samples of wallboard were dried, then soaked in solutions of hygroscopic salts, and redried. Sodium hydroxide and calcium chloride were used. The former caused severe degradation of the fiber; the latter caused no apparent damage on short term exposure, but it was noted that long term exposure of the treated fiber to a moist atmosphere resulted in considerable swelling.

The results of this study are presented in tabular form in Table VI, Appendix, but may be summarized here. Three types of wood pulp were investigated; a highly purified white material in sheet form, known as "dissolving grade pulp", a commercial sample of Kraft process pulp in sheet form, and a sample of the product of an experimental continuous pulper. The latter material in random lump form was the least purified of the materials investigated. The three pulps were sampled in their "as received" condition and it was found that in this condition their moisture content ranged from a minimum of 2.7% for the white pulp, to a maximum 4.7% for the Kraft pulp.

Samples of the pulps were then exposed to a controlled atmosphere of 80% relative humidity at 80 F for several days and the equilibrium moisture content determined. This averaged 14% for the white pulp, 20% for the Kraft, and 21% for the bulk pulp from the continuous digester. These values were later used to "subtract out" the normal moisture absorptivity of the fiber when chemically treated samples were investigated.

For the chemical treatments, four solution strengths were utilized, ranging from a saturated solution through 40% chemical by weight, 20% by weight and 10% by weight. As noted previously, two hygroscopic chemicals were used, sodium hydroxide and calcium chloride. The former was taken as an example of the chemically active desiccants such as the alkali oxides and hydroxides and the strong mineral acids. The calcium chloride was selected as an example of a hygroscopic salt, and in particular of a salt which in its reaction with moisture, went through several stages of hydration. Other similar materials are the halides of the alkali metals. (LiBr, NaCl, etc.). These "salts" are not so corrosive as the strong bases and acids, but in general do not have as great an affinity for water.

Calcium chloride, with a formula of $CaCl_2$, differs from some other desiccant materials in the fact that it has four solid crystalline forms, all of which have the ability to absorb water vapor from humid atmospheres, although this ability varies widely among the four forms. These are, anhydrous calcium chloride, $CaCl_2$; the monohydrate, $CaCl_2 . H_2O$; the dihydrate, $CaCl_2 .2 H_2O$; and the hexahydrate, $CaCl_2 .6 H_2O$. If anhydrous calcium chloride is exposed to humid air with a relative humidity of over about 30%, the dry salt will progressively become hydrated by the absorption of water. If it in turn is exposed to humid air, it continues to absorb moisture to form a solution of calcium chloride in water. This solution attempts to reach an equilibrium with the water vapor in the air, and this equilibrium ranges from a 50% calcium chloride brine in contact with air at about 25% relative humidity to a 21% brine in contact with air at 80% relative humidity. As moisture is absorbed, heat is liberated; the amount of this heat being equal to the heat of condensation of water vapor at the existing temperature, plus a heat of crystallization, and/or solution. This is a rather impor-

tant disadvantage of the chemical absorbents as compared to mechanical refrigeration.

The method of conducting the tests was as follows: Samples of pulp sheets approximately 1 1/2 inches square or lumps of bulk pulp, approximately five grams in weight, were dried to constant weight at 105 C. These samples were then immersed in a room temperature solution of treating chemical, pushed under the surface and manipulated against the bottom of the container until it could be ascertained that all air had been driven out from among the fibers. The samples were then removed and allowed to drain for ten minutes, then dried at 105 C to constant weight. The dried samples were subsequently exposed in a small chamber made of polyethelene film and equipped with humidifying pans. Periodic checks were made with an aspirating psychrometer to determine the environmental conditions within the chamber. The solutions employed were made up using laboratory grade reagents and distilled water. The saturated solutions first employed were maintained in that condition by providing an excess of the solid chemical. The solutions of 40%, 20%, and 10% subsequently used were made up by mixing known weights of chemical and water. They were used once and then discarded.

It was found that the use of sodium hydroxide resulted in degradation of the cellulose with the production of a wetted sample with essentially zero mechanical strength and when the saturated solution was employed, the degradation was so severe that semi-liquid pastes were produced on exposure to the humid atmosphere. Even when samples which had been treated with the 10% hydroxide solution were exposed, considerable loss of the tensile strength was noted and it was felt that the wetted material would present too many problems of support to be considered as a suitable lining material. The use of calcium chloride on the other hand, did not produce adverse effects on the samples, at least not to any greater extent than the normal weakening of a wood pulp material on wetting. In addition, the strong solutions employed, were not hazardous to handle as the sodium hydroxide solutions had been.

The performance of the chemically treated samples was evaluated in terms of an "efficiency" which was expressed as the ratio of the weight of water actually absorbed per pound of treating chemical to the weight of water that could be held by the pure treating chemical at equilibrium under similar conditions.

These latter values were five pounds of water per pound of sodium hydroxide and 2.8 pounds of water per pound of calcium chloride, both values being computed for the condition of 80 F and 80% relative humidity. It should be noted that in the computations, the water which the untreated sample would have absorbed has been subtracted from the total amount absorbed.

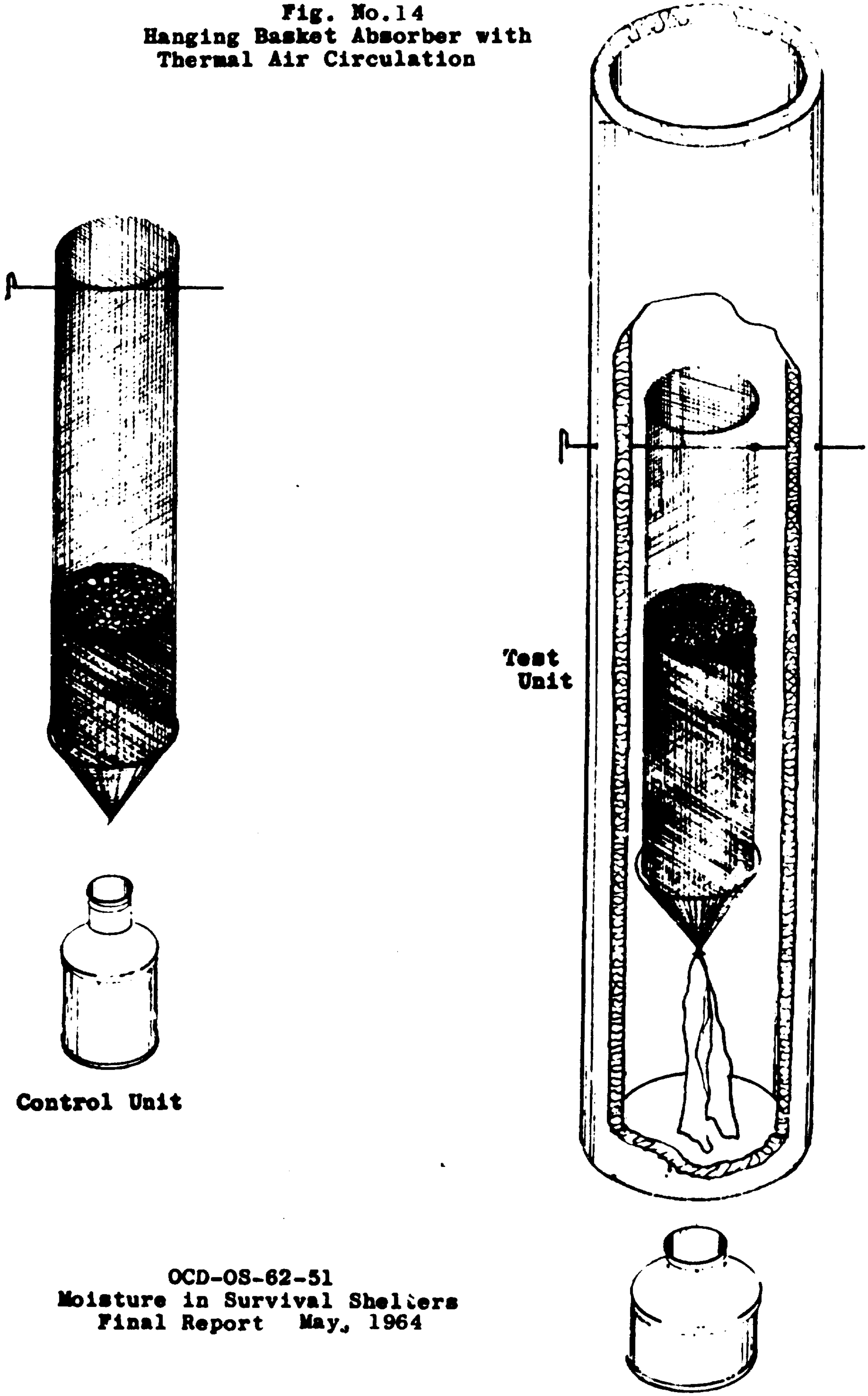
Also, in the case of treatments involving calcium chloride solutions, the material which is considered to be retained on the dried fibers is the dihydrate, $Ca(Cl)_2.2\ H_2O$, since the last two molecules of water would be driven off only by raising the drying temperature above 175.5 C.

Had the chemical treatment worked as anticipated, the samples would have absorbed more water than could have been held by both their pulp content and their chemical content taken separately. That is, the chemical would have acted as a "getter" and the pulp as a "sponge" to absorb the water resulting from the chemicals' action. Unfortunately, this did not occur. When the results of Table VI are examined, it can be noted that the highest efficiency was 88%, that is about 12% more water would have been absorbed if the chemical had been employed alone. Against this loss in efficiency might be weighed the possible extra convenience of a treated panel as compared to the necessity of providing trays, containers, etc., with which to expose the pure chemical. It may be noted as a general trend, that the rather harsh pulp from the experimental continuous digester, performed somewhat better than the highly purified pulp, that calcium chloride had a higher efficiency than did sodium hydroxide, and that better utilization of the absorptive capacity of the chemical was obtained by the use of the lower levels of treatment.

Absorption Dehumidification (By pure chemicals). The third approach to the problem of dehumidification of shelter spaces by integral dehumidification equipment or methods, involved the use of desiccant chemicals brought into direct contact with the humid atmosphere. The general idea of utilizing a chemical water absorber immediately introduced the problem of how the humid air was to be brought into contact with the chemical, and the ensuing problem of what was to be done with the resulting spent chemical, or in the case of calcium chloride, with the brine which results from complete utilization of its absorbing capacity. As just discussed, one possible solution involved the preparation of a composite wall structure with both absorptive and retentive capacities. A second solution was to design various moist air-chemical contactors with provision for storing the spent brine.

As one method of exposing calcium chloride to moist air, a hanging wire mesh basket was constructed with an accompanying reservior to hold the brine produced. An additional feature was an insulated duct surrounding the basket, the purpose of which was to conserve the heat of the dehumidification reaction within the dried air, thus setting up a thermal current which resulted in positive circulation through the drying apparatus. A wick added to the bottom of the basket served to contact the strong brine with additional moist air and the whole device operated with countercurrent flow of brine and moist air, the partially dried air finally contacting nearly anhydrous calcium chloride as it rose. The basket with insulated duct and wick is shown in Figure 14.

Fig. No.14
Hanging Basket Absorber with
Thermal Air Circulation



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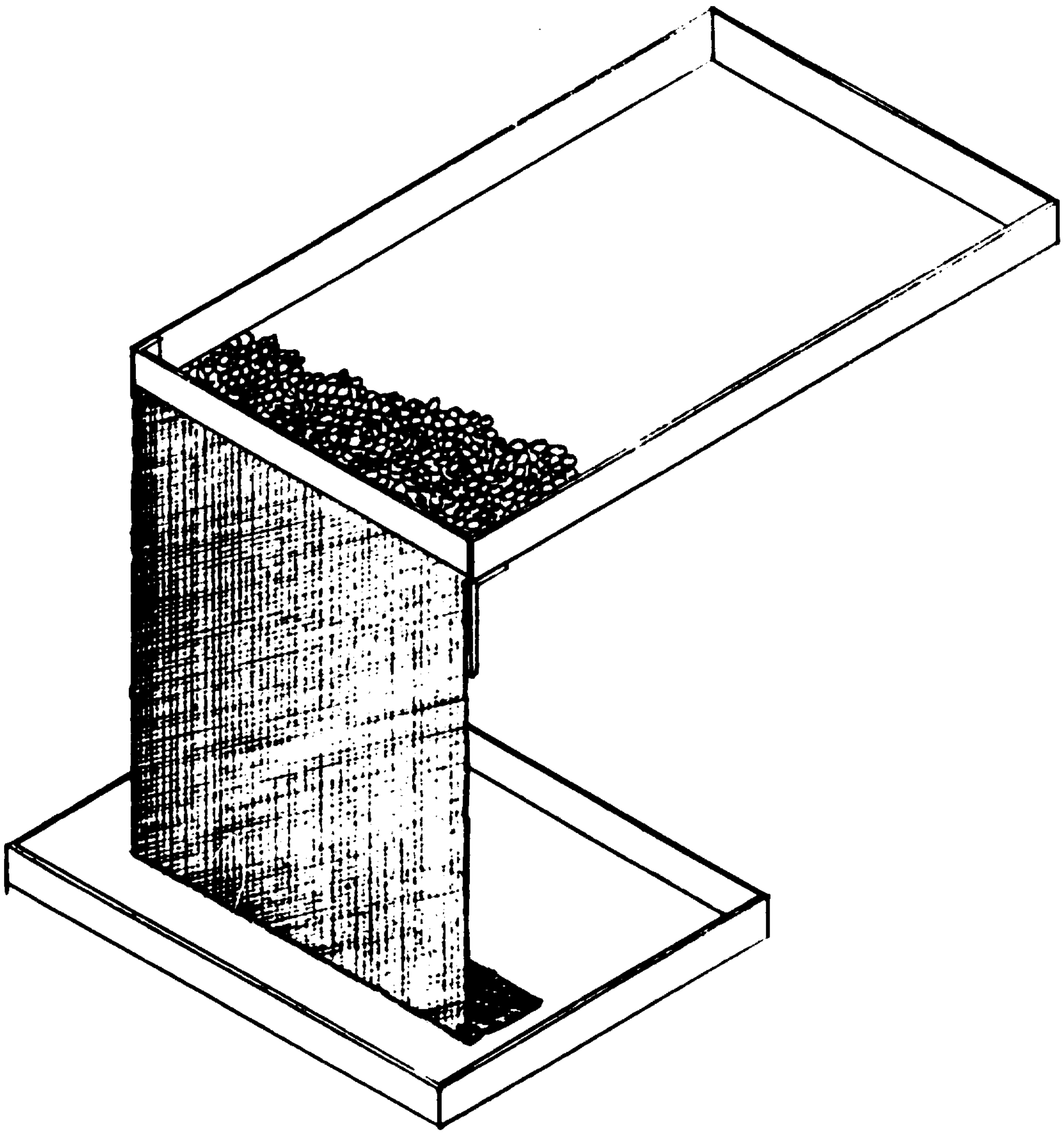
Tests of the insulated unit did not demonstrate a conclusive advantage over the bare basket. In the first tests, the insulated duct unit produced somewhat less brine than the exposed basket, but this brine contained slightly less calcium chloride (55.7% vs 57%) than did that from the open basket. However, in subsequent tests, this trend was reversed and the brine from the insulated unit was more copious but stronger than that from the other unit. This led to the conclusion that a thermal current was actually set up in the duct, resulting in a greater flow of moist air past this unit than past the bare basket but that exposure of the strong brine to additional moist air was inadequate. Later work with wicks of varying lengths indicated that the wick employed with the hanging basket was too short. Further, theoretical analysis of the properties of the air as it is dried, indicated that only a very slight convection current may be expected. Although heat is released by the reaction between calcium chloride and atmospheric moisture, and this heat remaining in the dried air causes it to expand and thus have a lower density, there is an opposing effect of almost equal magnitude.

The removal of moisture from the air, since it amounts to removing a component of lower molecular weight from a mixture, actually leaves the dried air with a higher density than the moist air. The loss of density due to heating and the increase of density due to drying, nearly cancel each other. There is however, a slight net loss in density, so that upward flow through the apparatus may be expected. Coupled with gravity flow of the brine, this results in countercurrent operation. It was felt however, that the slight gain in performance of the ducted apparatus over the control unit did not warrant the extra complexity of the design, so simpler contacting devices were constructed.

In an attempt to cause the partially spent calcium chloride brine to come more nearly to equilibrium with the surrounding moist air, a series of trays were constructed and equipped with wicks of huck towelling material. Details of construction of the trays and wicks are shown in Figure 15. The trays were charged with 1 1/2 pounds of anhydrous calcium chloride each, which resulted in a layer of granules about 1/2 inch deep. At the onset, while the initial reaction between the anhydrous calcium chloride and water vapor to form the hexahydrate ($CaCl_2.6\ H_2O$) was taking place, pairs of trays were allowed to discharge into common containers. These containers consisted of flat pans 2' x 2' x 1 1/2" deep.

Fig. No. 15

Tray-type Absorber with Wick-Pilot Size



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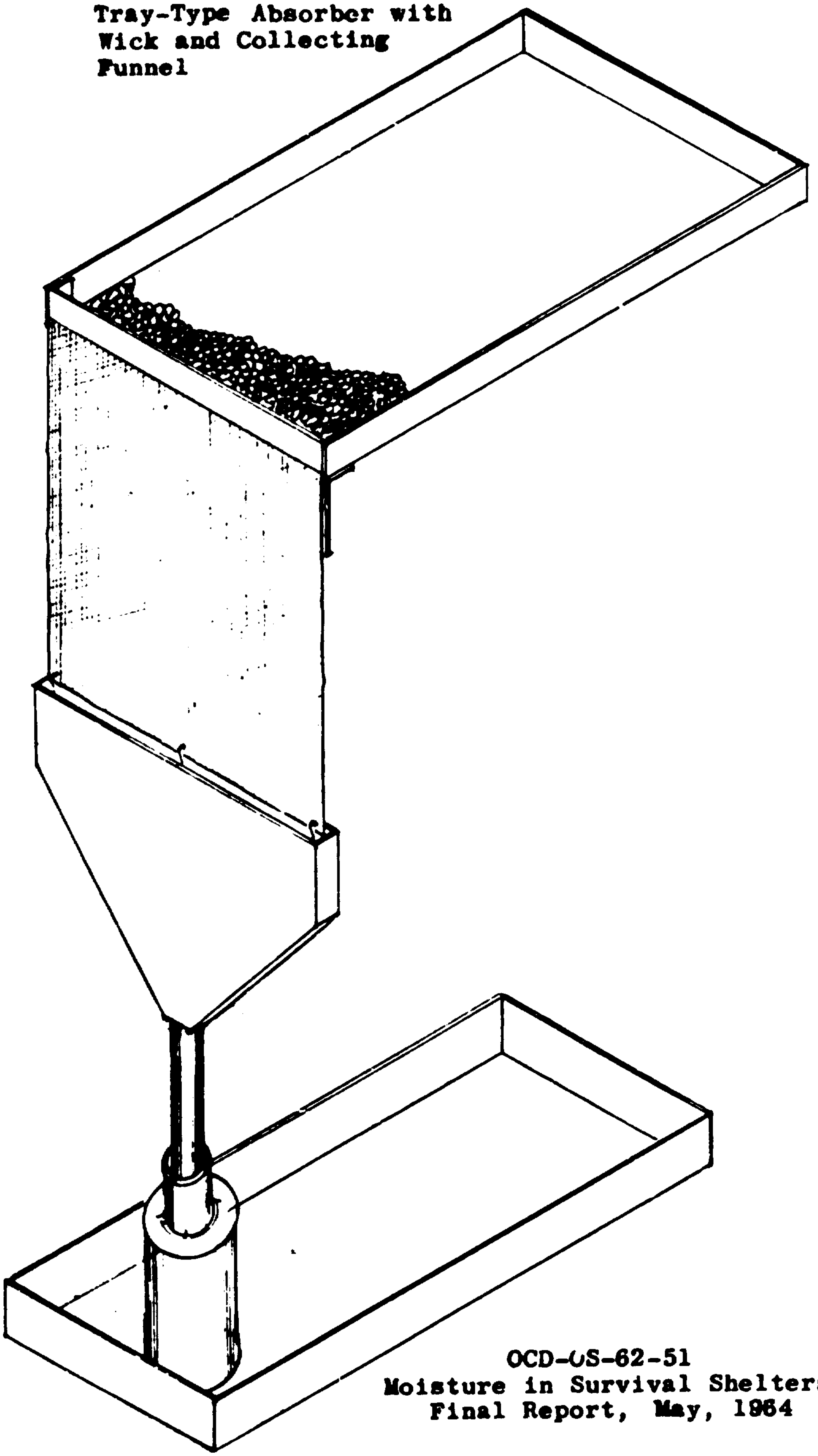
Due to the press of other work, the experiment was not examined for about two and a half days, at which time it was discovered that all of the calcium chloride had been exhausted and the container trays contained a considerable quantity of brine. This latter was sampled and it was noted that the tray which had received the brines from absorbing trays 1 and 3 (with wick lengths of 2 3/4 and 10 1/2" respectively) contained a brine of 35.6% calcium chloride. The other receiver which had collected the brines from absorbers 2 and 4 (with wick lengtns of 4 1/2 and 23 1/2" respectively) held a brine which had a calcium chloride content of 33.2%, or about 2 1/2% weaker. Thus, it appeared that the longer wicks of trays 2 and 4 (a total of 28") had been slightly more effective than the combined action of trays 1 and 2 with their total wick length of 13 1/4".

All of the absorbing trays were recharged with anhydrous calcium chloride, although no attempt was made to measure the weights of chemicals used. Each absorbing tray was equipped with its individual receiver. At the end of about twenty-one hours the experiment was re-examined and it was noted that some undissolved calcium chloride remained, (probably $CaCl_2.6\ H_2O$) although the amount in each tray differed. The brines in the receivers were sampled and it was found that the calcium chloride concentration varied as a function of the wick length as had been expected, but it was also noted that the variation was not at all linear, nor was the weakest brine (from the longest wick) nearly as dilute as the ambient humidity would have produced if equilibrium had been reached. Thus, the weakest brine produced still contained 32% calcium chloride, while the chamber conditions of 78 F dry bulb, 80-82% relative humidity should have produced a brine containing only 20 to 22% calcium chloride.

The experiment was allowed to proceed another twenty-four hours when it was noticed that the calcium chloride supply in trays 3 and 4 was completely exhausted while a few granules remained in trays 1 and 2. A sampling of the brines indicated very little concentration variation with wick length. Only tray 1 with its very short wick had produced a strong brine of 34% calcium chloride. The other three receiving containers held brines of from 23 to 25% calcium chloride, with the 25% brine resulting from the longest wick.

These anomalous results caused a re-examination of the experimental conditions. It was concluded that the area of the brine receivers was so great compared to the wick areas that probably water absorption by the collected brine completely masked the varying water absorptions occurring in and on the wicks. To obviate this, a flat funnel was constructed and used as shown in Figure 16.

Figure 16
Tray-Type Absorber with Wick and Collecting Funnel



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To get the widest possible data spread, the funnel was first installed on tray 1 with its short (2 3/4") wick. It was noted that five hours were required before sufficient brine was formed to wet all the granules and start liquid to dropping off the end of the wick. The brine was protected from further water absorption by being delivered into a narrow necked receiver and was sampled three times over a period of forty-one hours. The calcium chloride content varied from 48.0% to 48.5%, reaching a high value of 51.0% at the end of approximately twenty-five hours. These concentrations correspond to nearly pure $CaCl_2.6H_2O$, thus the effect of the wick was negligible as had been expected for such a short length of cloth.

The experiment with the funnel to protect the wick effluent was repeated using the longest wick, number 4 with a length of 23 1/2 inches. First, it was noted that even after seven hours, no brine had left the wick. By the next morning, however, brine was being produced copiously and measurements began. At the end of eight hours, sufficient brine had been collected to determine its concentration at 34% calcium chloride, it can be seen that a longer absorption time was needed. This particular series of experiments was suspended at this point and not afterward resumed. However, additional information about the length of wick required to ensure saturation of the brine may be obtained from the tests in a fallout shelter which are reported in the next section.

Absorption Dehumidification (Shelter Tests). As a preliminary to more elaborate tests, two trays of anhydrous calcium chloride were introduced into a tank type shelter in which a small scale simulated occupancy test was in progress. At the time this experiment was begun, the ambient conditions in the shelter were 81 F dry bulb and 98% relative humidity. The shelter was being supplied with a total of ten cubic feet per minute of outside air whose relative humidity varied from a high of 95% in the early morning hours to 45% shortly after noon.

The flat trays, 2 feet on a side and 1 1/2 inches deep were each supplied with 2.5 pounds of anhydrous calcium chloride, spread in a layer about 1/4 inch deep. At the end of forty-two hours, the pans were emptied and the brine sampled. A few undissolved granules remained in each pan; the total amount remaining was estimated at not more than 1/4 pound. The calcium chloride content of the brine was 44.7%. The relative humidity within the shelter had been reduced from 98% to 89%.

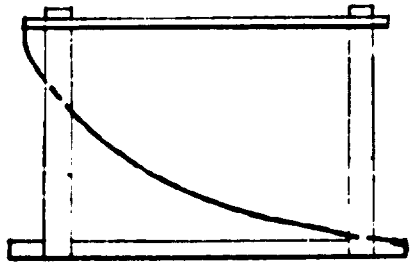
To greatly increase the area available for absorption, and to provide a means whereby saturated $CaCl_2 \cdot 6H_2O$ brine could be further contacted by moist air while separated from its solid phase, trays were constructed on the order of those already described in another section, but with the provision of a slanting wick and a receiving pan of area slightly greater than that of the pan holding the solid calcium chloride. A typical pan, wick, and receiver are shown in Figure 17, View A.

The new pans were installed and charged with anhydrous calcium chloride. At the end of 14 1/2 hours, the experiment was visited and it was observed that both sets of equipment were operating. However, when the brines were removed and tested, it was found that they differed both in total amount and in concentration. It is suspected that the air circulation within the shelter caused by the localized introduction of ventilation air, may have been responsible for the difference. The brine present in lesser amount had a concentration of 44.0% calcium chloride, while the larger quantity resulting from the second unit, contained 35.2%. During this period of the test, the shelter conditions had averaged 81% relative humidity for which the equilibrium calcium chloride brine would have contained about 22% calcium chloride.

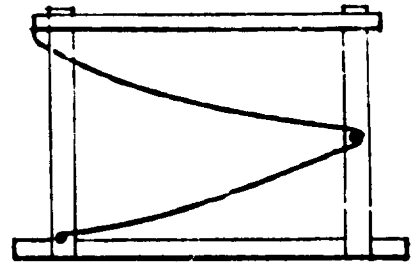
The experiment was observed again after a total of twenty-two hours had expired. At this time the humidity within the shelter had been reduced to 73%. The quantity of brine in the lower pans was nearly equal (some of the brine from one pan was spilled while being transferred, so no exact comparison can be had). The concentrations were 40.0 and 43.0% calcium chloride. For the 73% relative humidity condition, the equilibrium brine would have been 26.5%.

Figure 17

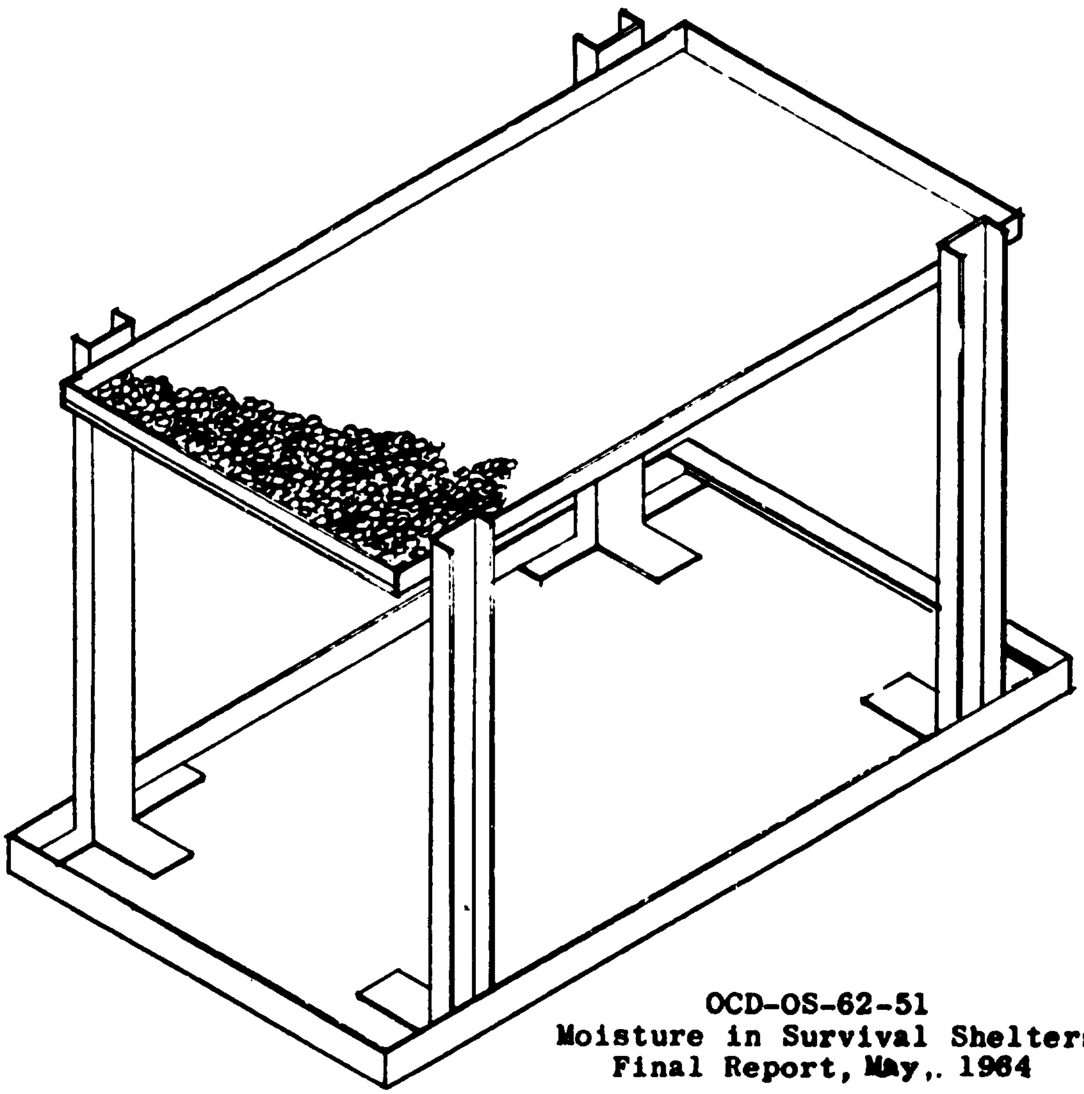
Tray-Type Absorber with Wick-Shelter Size



A. Original wick configuration



B. Final wick configuration



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Due to a failure in other apparatus, the water feed to the simulated occupants was interrupted for a period of hours and the relative humidity within the shelter decreased to 67%. The entire simulated occupancy test was shut down over the ensuing week-end, but the absorption trays were allowed to remain. When examined approximately forty-eight hours later, the pans were found to contain identical amounts of brine of almost exactly the same concentration (31.0 and 31.2% calcium chloride). Apparently, the long period of exposure had sufficed to smooth out any moisture gradients existing within the shelter. Unfortunately the final humidity in the shelter was not determined, so that the approach of the brines to equilibrium can only be surmised. The equilibrium relative humidity for this value of concentration would have been 60%.

From this test, however, it was concluded that the length of wicking employed was insufficient to adequately expose the strong brines to further absorption. A minor redesign of the trays shown in Figure 17, View B was made. Severe corrosion was noted in the vicinity of every spot weld in the pans, pointing up the need for some though being given to materials of construction if dehumidifiers employing calcium chloride are envisioned.

The absorption pans with the modified wicks were placed in service at 1630 on Thursday, May 24. At this time the relative humidity within the shelter was 77%. The shelter was being operated with two simulated occupants and a total ventilation rate of ten cubic feet per minute. By 1930 that same evening, the relative humidity had been reduced to 74%, but it was noted that at some time during these first three hours, the water feed to one "Simoc" had been interrupted and it was dry. The difficulty was corrected and the test resumed. At this time, no evidence was noted of brine flow along the wick, in fact the granules of calcium chloride were no more than damp.

The experiment was examined at 0830 on Friday after a lapse of sixteen hours when it was noted that both "Simocs" were functioning properly and the relative humidity within the shelter was 73%. There was some brine present in the lower pans but it was not sampled at this time. Two hours later the shelter was again visited. The relative humidity had risen to 76%. One of the wicks was wet all over and had produced 2.52 pounds of brine with a concentration of 38.5% $CaCl_2$ (cf equilibrium concentration of 24.0% $CaCl_2$ @ 76% R.H.). The wick on the other unit, in contrast, was hardly wet at all, and the brine could be observed standing above the fibers of the cloth in more or less spherical droplets which eventually ran toward an edge of the wick and from there dropped to the receiving pans below. This condition was readily corrected by "priming" the dry cloth with some water free from calcium chloride following which the strong brine was immediately absorbed into and wet the cloth.

At 1610 Friday afternoon, the shelter was again examined in order that the first twenty-four hour period of the test be well documented. The relative humidity had dropped to 72%. The receiving pans contained brines of 42% and 45% $CaCl_2$, with the more dilute solution in the unit which had been working well from the beginning. For the 72% humidity condition, the equilibrium solution would have contained 26% $CaCl_2$.

By 0915 the next day (Saturday) it could be noted that bare spots were appearing in the original continuous layer of calcium chloride granules. At the same time it was observed that the relative humidity had risen to 82%. The production of brine had continued and the pans contained solutions of 39% and 30% $CaCl_2$, with the weaker solution resulting from the same unit which had functioned best all along. The solution in equilibrium with 82% relative humidity contains 21.5% $CaCl_2$.

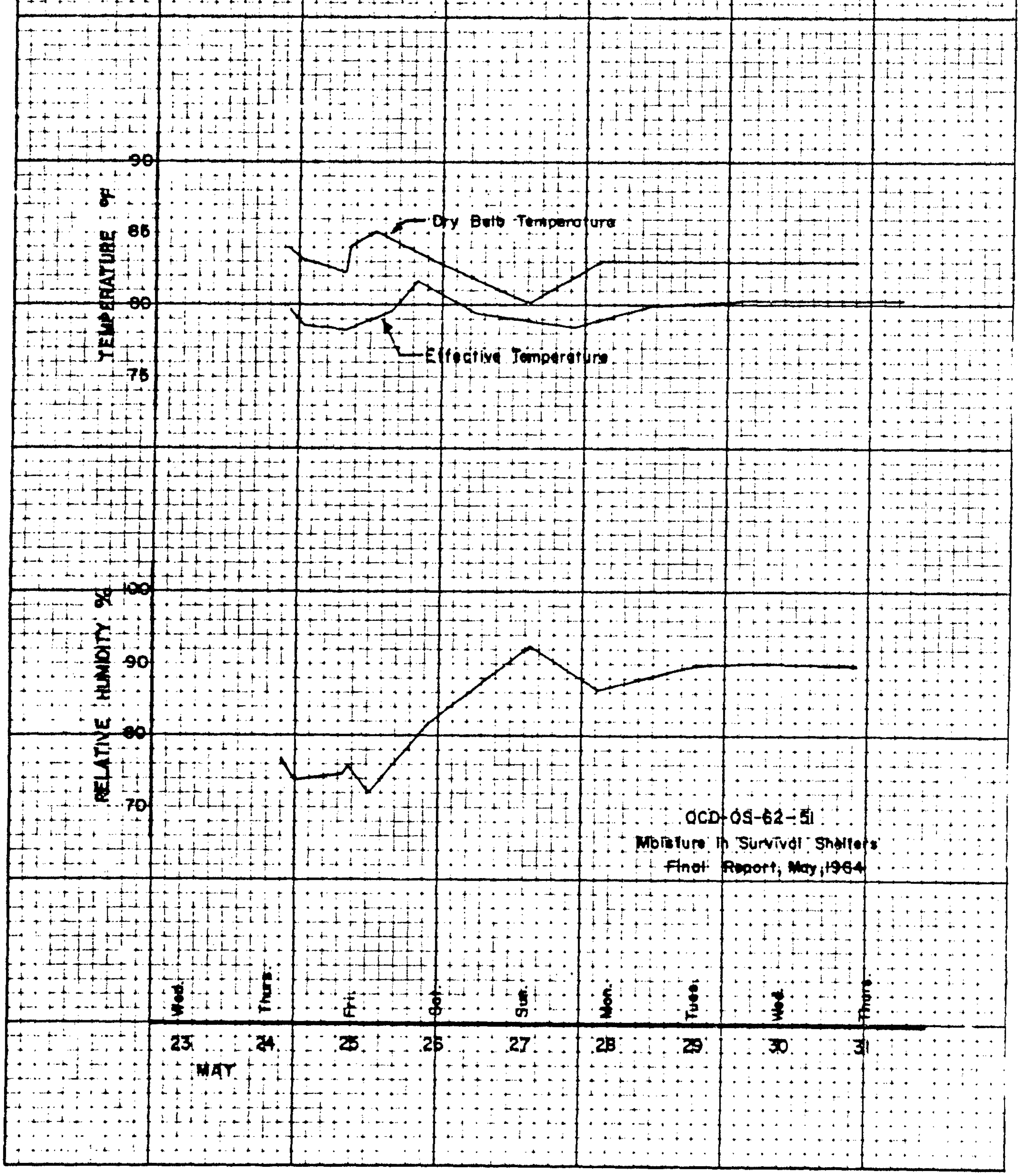
On Monday, the experiment was obviously almost over. No granules of calcium chloride were visible, but the upper pans and wicks were still wet. Only a total of 1.4 pounds of additional brine had been produced during this last forty-eight hours. The two units produced brines of 24% and of 21% $CaCl_2$. Again the same unit had produced the weaker brine. The shelter humidity had risen to 87%, for which the equilibrium brine would have contained about 19% calcium chloride.

Here it might be noted that the unit which consistently produced the weaker brine, i.e. the unit which was doing the most effective job of utilizing the dehumidifying ability of the calcium chloride, was located closest to the ventilation air inlet. In addition, the wicks, although of the same basic huck towelling material, were dyed different colors, and it was learned in subsequent work using these cloths that the dye treatment made a great difference in their wetability.

The results of the experiment just described are presented in graphical form as Figure 18 and in the Appendix as Table VII. In retrospect, one could wish that the data had been taken at more frequent intervals, however, the experiment was deemed to be of an exploratory nature at the time it was conducted. Subsequently, the authors became more and more convinced of the futility of self-contained dehumidification methods and devices so that the experiment was not repeated.

FIG. NO. 18

ENVIRONMENTAL CONDITIONS IN PROTECTIVE SHELTER DURING ABSORPTION DEHUMIDIFICATION TEST SUMMERLIN SHELTER



Also, it became evident that hourly fluctuations in the icro-meteorological environment were great enough to mask all ut the most positive experimental trends. (Later work involing dehumidifiers with external heat sinks was conducted using source of ventilation air whose temperature and absolute humiity could be carefully controlled). From Figure 18 it may be nferred that dehumidification began immediately after the calium chloride was exposed. During the first twelve houis the umidity was reduced to 74 - 76% and held there, although there as not the immediate rise in shelter temperature that had been xpected. Reference to Table VII indicates that during this ime the desiccant material had absorbed 38% of the water reeased by the simulated occupants. During the next twelve hours, ehumidification was accelerated, there was a slight additional ecrease in relative humidity and a sharp rise in shelter temerature. Also, from Table VII it can be seen that at the end f the initial 24 hour period, the calcium chloride had absorbed 9% of all the water released by the occupants. This rate of bsorption continued through the next observation (after 41 hours f operation). From Figure 18 it can be seen that in spite of his, shelter humidity began to rise and shelter temperature to all.

A factor that would tend to produce the results depicted n Figure 18 is the relatively high heat of hydration of calium chloride. The various heats of hydration, all based on ne pound of anhydrous calcium chloride are, 98.7 Btu per pound o form the dihydrate, 269 Btu per pound to form the tetra-hyrate, and 379 Btu per pound if the hexa-hydrate is the end roduct formed. The heat of solution of the hexa-hydrate is, owever, negative, being -70.4 Btu per pound. Considering the rrangement of the experimental apparatus, it seems certain hat all of the initially anhydrous calcium chloride was hydraed to the hexa-hydrate form, before any strong brine was prouced. Thus, for every pound of water condensed and absorbed uring this phase of the experiment, a total of approximately 096 plus 379 or 1475 Btu were released. After all $CaCl_2$ had een converted to $CaCl_2.6\ H_2O$, the next water condensed liberated 096 minus 70 or about 1026 Btu for each pound. This represents 30% reduction in heat of condensation during the final phases. lthough the net liberation of heat due to water absorption might e reduced by starting with the calcium chloride in the completely ydrated form, the economics of the drying process are against his. A pound of the original anhydrous material can absorb 3 1/2 ounds of water in being converted to the 22% solution in equilirium with an atmosphere of 80% relative humidity. If the calcium hloride is already in the hexa hydrate form ($CaCl_2.6\ H_2O$), before eing exposed in the shelter, it has an initial water content of .97 pounds of water per pound of calcium chloride. In going to he 22% brine, it can absorb an additional 2 1/2 pounds of water. loss of approximately 29% of its absorbing ability has been ustained.

The results of the experiment just described do not bear out in every detail the previously discussed theory in the section entitled Thermodynamics of Dehumidification. The overall agreement, however, is good, and in particular it may be concluded that where chemical dehumidification is being actively pursued, there will be a rise in both the dry bulb and in the effective temperature of the space being conditioned. It might be noted here that the experiment in the shelter differed from that postulated in that there was a continuous circulation of air through the shelter, and during the evening hours at least, this air was cooler than that in the shelter.

It might be possible to maintain the absolute and relative humidity at a point where rust and mildew would be controlled in closed, unoccupied shelters by means of open trays containing $CaCl_2$, and thereby keep such a shelter in a standby condition. If this procedure were contemplated, the shelter ventilation system should be closed off, and all openings made as air tight as possible, to prevent continual interchange of dried shelter air with possible moist outside air. If such interchange is permitted, the calcium chloride will be rapidly depleted and the temperature in the shelter may rise due to liberation of the heats of condensation of water and hydration of calcium chloride.

IV. ENVIRONMENTAL CONTROL METHODS AND DEVICES WITH EXTERNAL HEAT SINK.

The Control of Shelter Environment by Excess Ventilation Air. Consideration was given to the possibility of removing sensible and latent heat which had been added to the shelter air by occupants, by purging the shelter with an excess of unconditioned outside air. It would appear that if sufficient air were supplied to a shelter, it would be possible for climatic conditions within the shelter to approach climatic conditions that existed outside the shelter. In fact, ventilation air drawn into the shelter during relatively cool nights could possibly be utilized to cool the walls of the shelter and the earth surrounding these walls. It is not impossible to assume that sufficient heat storage capacity could be achieved to result in an overall improvement of the climatic conditions inside the shelter as compared to those outside the shelter. In order to test this theory, a series of tests were conducted in survival shelters which were occupied by simulated occupants. Air flows to these shelters were varied, and the resulting changes in climatic conditions within the shelter were recorded.

The following discussion is related to a twelve occupant shelter, partially buried, and constructed of poured concrete floor and roof and concrete block walls with a floor area of 120 square feet and a ceiling height of seven feet four inches. (See Figure 2). The results shown in Figure 19 indicate that with a ventilation rate of three cfm per occupant, conditions within the shelter would not be suitable for human occupancy if an 85 F effective temperature was used as an upper limit of human tolerance. This was concluded since immediately after the ventilation air flow was reduced to three cfm per occupant, the effective temperature went above 85 F and peaked at 89 F. The effective temperature was not below 85 F at any time during the forty-eight hours duration of this portion of the test. Data taken during another phase of this test indicate that ten cfm per occupant maintained an effective temperature of something less than 85 F. With 6 cfm per occupant, the effective temperature was slightly in excess of 85 F effective temperature for a short period. With three cfm per occupant, the effective temperature was above 85 F at all times; thus, it would appear that air flow in the order of 10 cfm per occupant would be adequate for maintaining conditions suitable for human occupancy in this particular shelter. It was possible to maintain such air flows with a 1/6 horsepower motor. A motor of this size could also overcome some energy losses in a duct and filter system, and would still be able to deliver ten cfm per occupant to a 12 man shelter.

The test previously described indicated that climatic conditions could be controlled in small family shelters by means of purging the shelter with outside unconditioned air. In order to test this theory on a large group shelter, the following test was conducted.

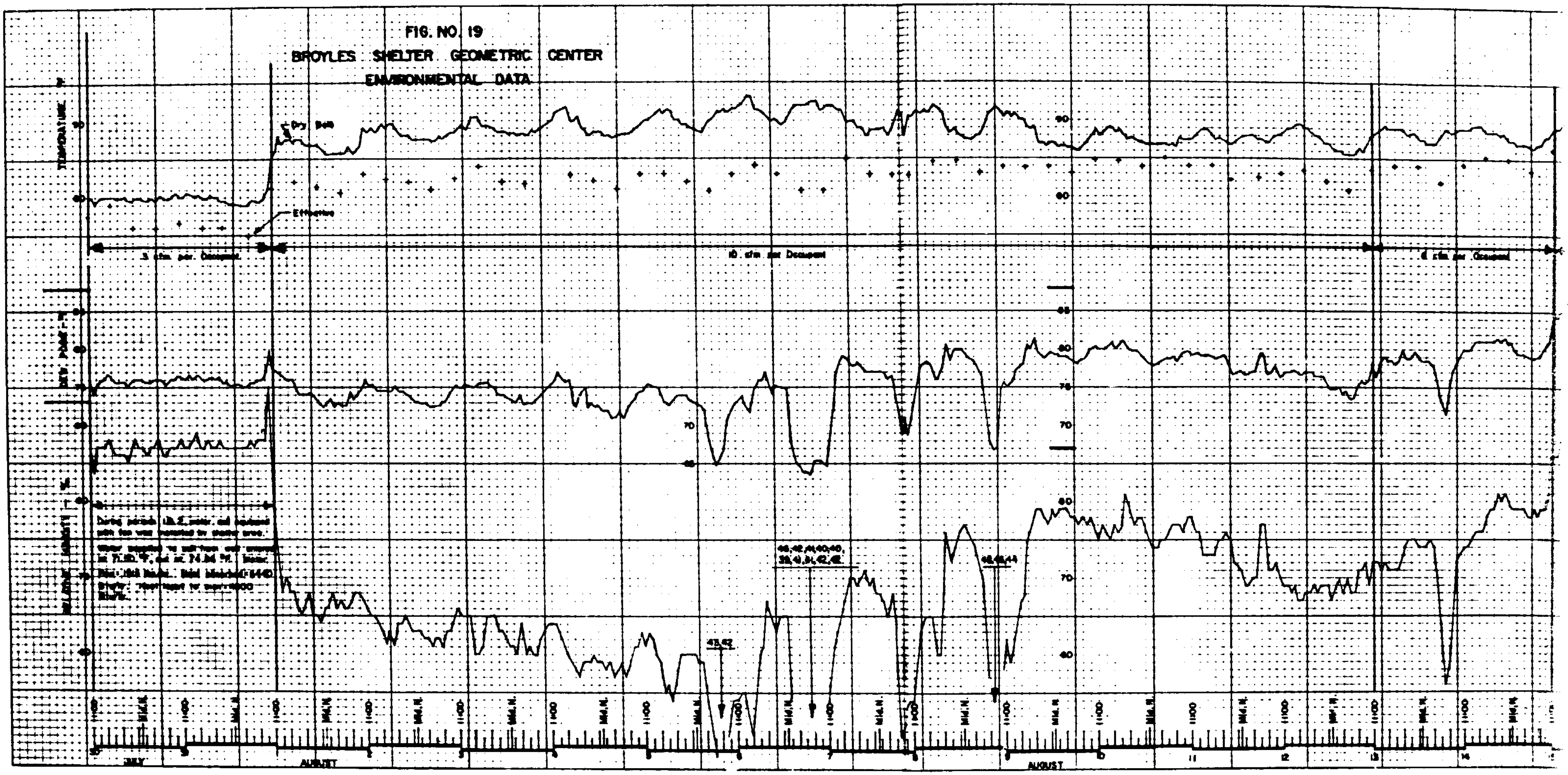


FIG. NO. 19
BROYLES SHELTER GEOMETRIC CENTER
ENVIRONMENTAL DATA
TEMPERATURE °F
Dry Bulb
Effective
.5 cfm per Occupant
10 cfm per Occupant
6 cfm per Occupant
JULY
AUGUST

Fig 19a

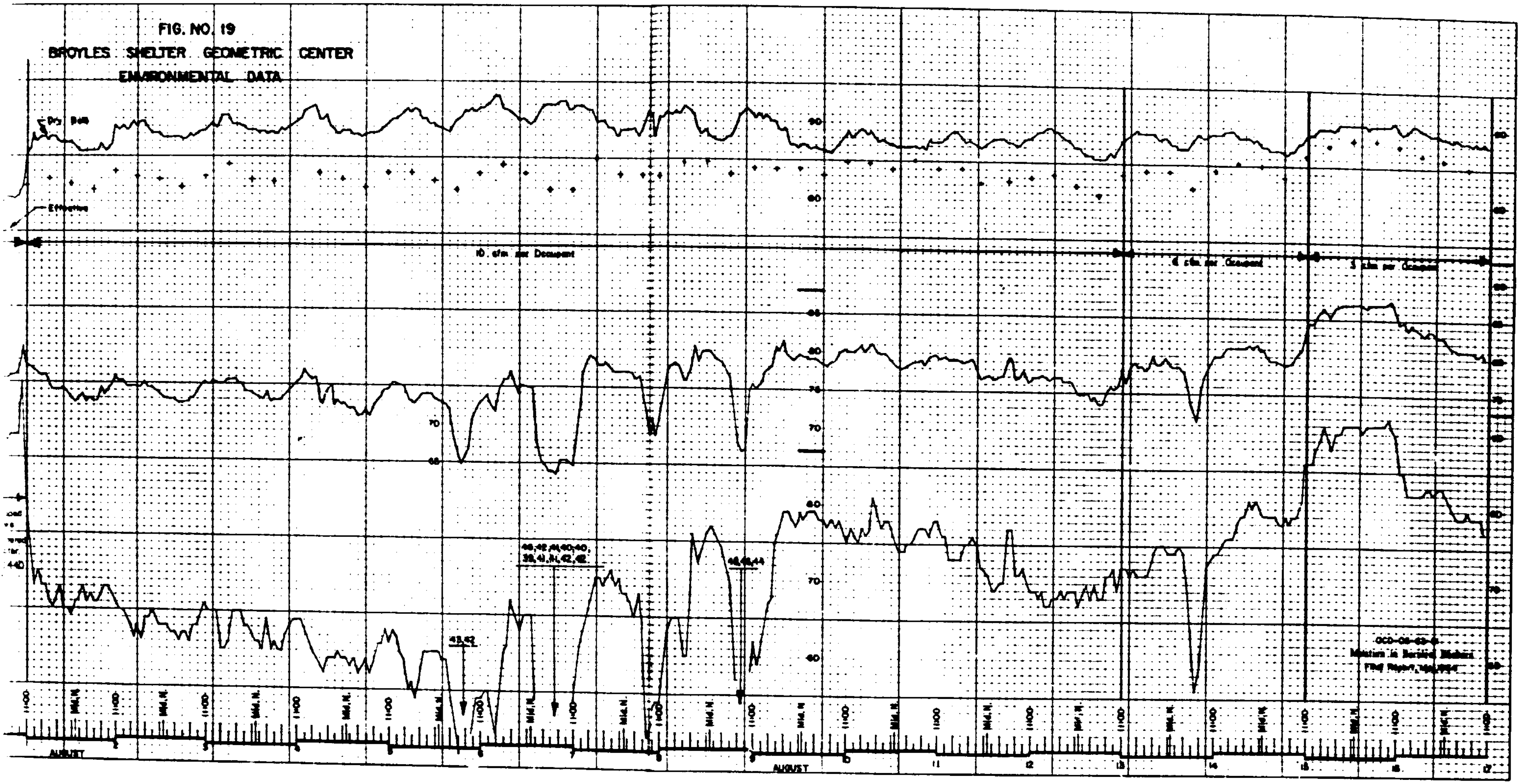


FIG. NO. 19
BROYLES SHELTER GEOMETRIC CENTER
ENVIRONMENTAL DATA
Dry Bulb
Effective
10 cfm per Occupant
AUGUST

Fig 19b

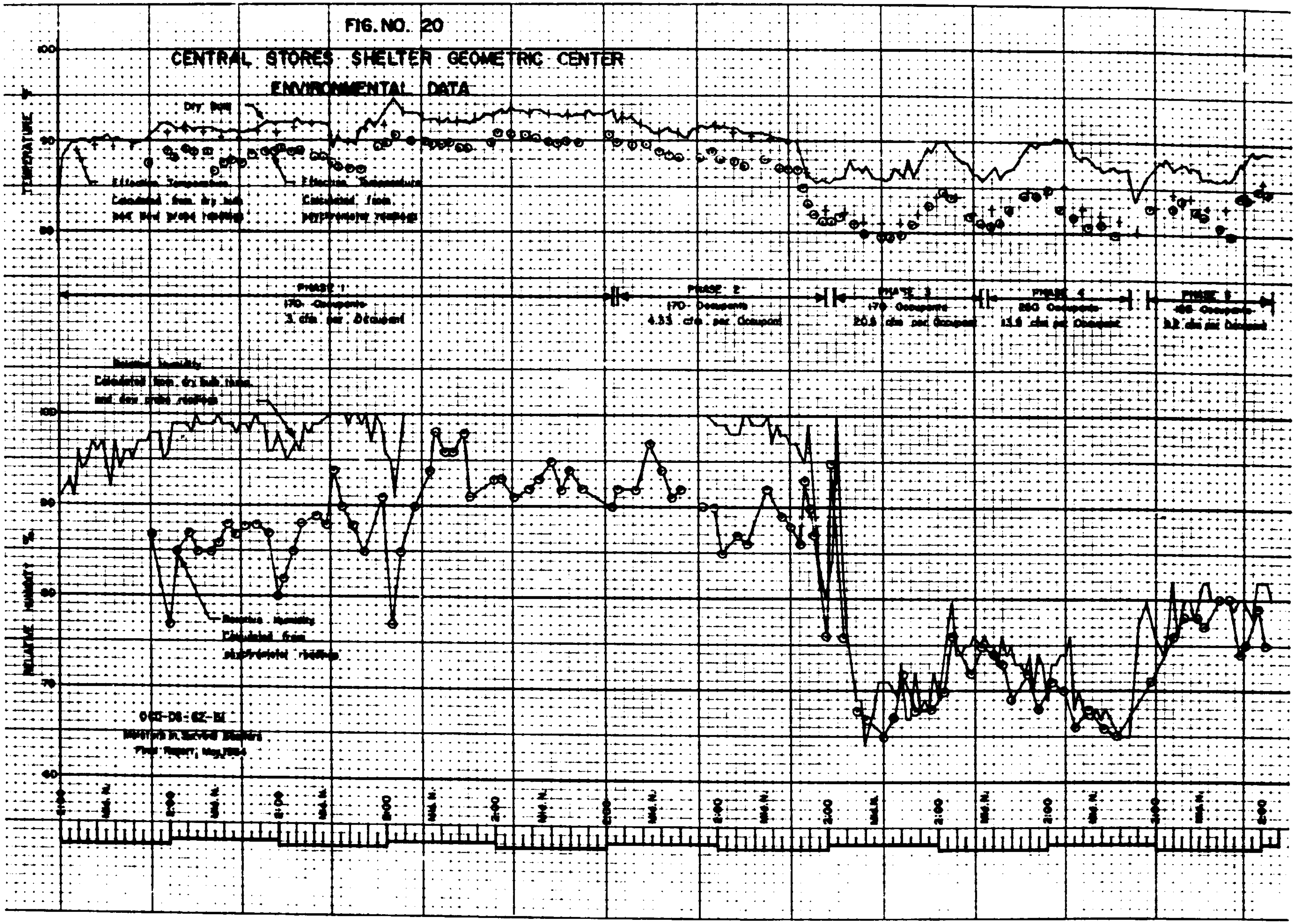
A shelter area in the basement of an existing building, suitable for occupancy by 170 occupants, was selected as a test shelter (See Figure 4). Since this shelter contained 2500 square feet, the 170 occupants had a floor area of approximately fifteen square feet per occupant. One test was conducted using 250 occupants so that some data could be obtained from this shelter under a floor area/occupant ratio in accordance with the Office of Civil Defense recommendations. This test was started September 14, 1962, with 170 occupants. Ambient temperature within the shelter was 83 F, and there was a total air flow of 510 cfm for an air flow ratio of three cfm per occupant. Within 2 1/2 hours the ambient temperature within the shelter had risen to 90 F, and the relative humidity had increased from 91% to 96%. (See Figure 20.) This test was continued for five days, and the relative humidity was 90%. A peak dry bulb temperature of 94.5 F was reached at the end of the third day, and a peak relative humidity was 98% at the end of the fourth day. At no time during this test period did the effective temperature go below 85 F, and for the last three days of this test the effective temperature varied from 89.5 F to 91 F. Again using 85 F effective temperature as the upper limit of human tolerance, it can be seen that with a ventilation rate of three cfm and 170 occupants that even with a floor area of fifteen square feet per occupant the conditions within the shelter would not be suitable for human occupancy. An undisturbed ground temperature, five feet below grade, of 81.5 F, was found in earth surrounding the shelter.

On September 20, 1962, the air flow was increased to 735 cfm for an air flow ratio of 4.33 cfm per occupant. Examination of Figure 20 indicates that increasing the air flow brought about a decrease of the dry bulb temperature, a decrease of the effective temperature, and a reduction of the relative humidity within the shelter during the second day of this phase of the test. However, the effective temperature did not drop below 87.5 F, and it was concluded that an air flow of 4.33 cfm per occupant was not sufficient to bring about habitable conditions within the shelter. On September 21, 1962, the air flow was increased to 3480 cfm, for an air flow ratio of 20.5 cfm per occupant. An examination of Figure 20 reveals that there was a marked reduction of the dry bulb temperature, the effective temperature and the relative humidity within the shelter. In fact there were long periods when the effective temperature remained at 80 F, and at no time during this phase of the test did the effective temperature exceed 85 F. This peak was held for a limited time. A similarity was noted in the cyclic nature of climatic conditions within the shelter as compared to a previous test performed on a small family shelter. This indicates that when sufficient air is supplied to the shelter to begin to bring about a habitable condition in the shelter, there will be a variation in shelter conditions related to the variation in outside climatic conditions.

FIG. NO. 20

CENTRAL STORES SHELTER GEOMETRIC CENTER

ENVIRONMENTAL DATA



The Use of Ground Water from Non-thermal Wells as a Means of Controlling Shelter Environment. The possibility of using ground water from a non-thermal well[1] as a means of dissipating heat generated in fallout shelters was considered worthy of exploration. A study of ground water temperatures at various locations throughout the United States indicated that any successful test conducted in Gainesville, Florida, would give information that would be valid for other areas in the United States, provided that the southern part of Florida be excluded from this comparison. Figure 21 illustrates how ground water temperatures vary in different locations throughout the United States.

A means of bringing the shelter air into contact with the ground water had to be devised so that the water could absorb heat from the shelter atmosphere.

A direct mixing process was found to be the most efficient from the standpoint of temperature and humidity control, since no barrier exists between the air which is to be conditioned and the fluid doing the conditioning when such a process is used. Thus it is possible to have conditioned air leaving such a device at the same temperature as the entering water. In conditioning a fallout shelter, this would be advantageous since it is desirable to take out as much of the moisture as possible and in southern climates to reduce the air temperature to a point approaching ground water temperature. A review of such a device was made from a practical operating standpoint, and it was found to have several disadvantages.

This device would be a sizable piece of equipment, and if it were located within the shelter it would occupy a considerable amount of useable floor space. Extensive duct work would be required to locate this device outside of the shelter. If installed inside, a second pump would be necessary for removing spray water from the shelter area. In view of these practical limitations, the idea of using a mixing process for temperature control and dehumidification, which would use ground water as a coolant, was abandoned.

The next method considered, consisted of a pump which would remove the water from the ground and supply it at a sufficient pressure so that the water could be forced through a coil which would be suspended in the shelter area.

A fan designed to circulate shelter air across such a coil would cause dehumidification and cooling to take place in the shelter air, provided that the fluid within the coil had a dew point temperature lower than the shelter air dew point temperature. By employing a counter flow principle, i.e., the coolest air being

[1]A non-thermal well is defined as a well that produces water at the same temperature in winter and summer.

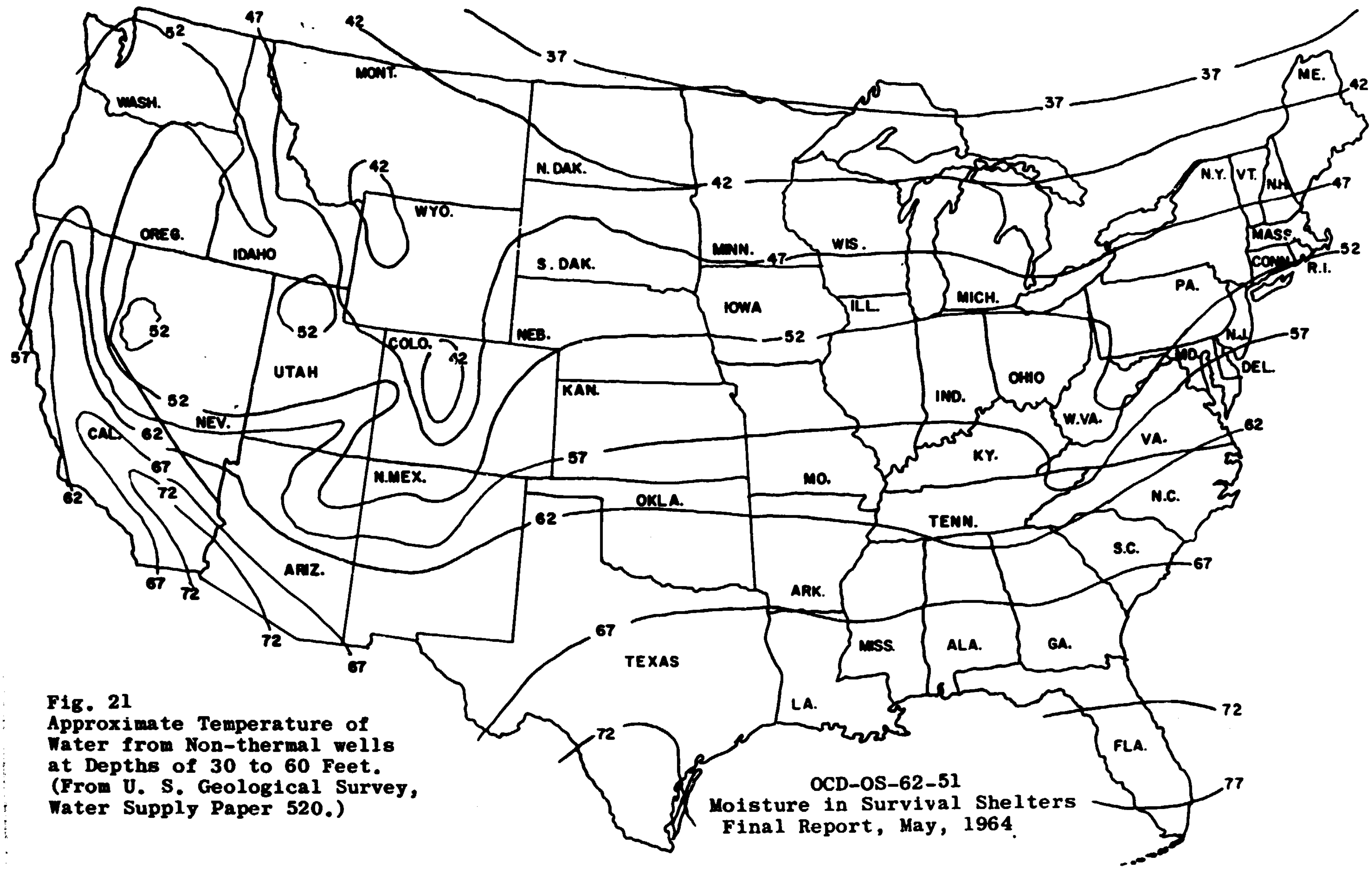


Fig. 21
Approximate Temperature of Water from Non-thermal wells at Depths of 30 to 60 Feet. (From U. S. Geological Survey, Water Supply Paper 520.)

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kept in contact with the coldest water, it becomes possible for the leaving air to approach the temperature of the entering water This flow arrangement enables a coil and fan system to overcome some of the heat transfer difficulties which are inherent in any system which imposes a physical barrier between the medium performing the cooling and the medium to be cooled.

It would be desirable to have relatively large flows of coolant and high coolant velocities through the cooling coils in order to obtain a uniform temperature throughout the coil. Conversely, it would be desirable to have relatively low air velocities across the coil so that the air might remain in contact with the cool surfaces of the coil for a relatively long period of tim

For the purpose of testing the efficiency of a system simila to the one described in the previous paragraphs, a coil and fan were installed in a shelter which was designed for occupancy by twelve people. This particular shelter was one that was being tested by means of simulated occupants and was being subjected to summer climatic conditions. The shelter contained 120 square fee of floor space and was equipped with twelve simulated occupants, each occupant releasing a total of 400 Btu per hour. The ambient temperature within the shelter at the start of the test was 81 F, and the simulated occupants were set to release 200 Btu per hour in the form of latent heat and 200 Btu per hour in the form of sensible heat. The shelter was a partially buried structure, which was constructed of reinforced concrete and concrete block with a minimum earth cover of three feet. The ground covering of the shelter was well sodded and was located in an area where direct sunlight would not impinge upon the earth covering the shelter due to numerous trees with heavy foliage (See Figure 2).

A seventy-five foot deep well was located adjacent to the shelter. The well was equipped with a jet-type pump which delivered the water at grade level with a positive pressure of 40 pounds per square inch. When pumped continuously, the water level in the well was twenty-five feet below grade, and water was delivered at a temperature of 71.50 F. This compares favorab. with the value of 72 F predicted from Figure 21.

Water from the well was routed through a serpentine copper c(in a counter flow pattern with respect to the air flow. Air was forced through the coil, 13.5 inches high by 20 inches long by 5 inches deep, by a 1/12 horsepower propeller type fan. The face area of the coil was 1.87 square feet and the average face velocit of the exit air was 450 feet per minute.

Ventilation air was supplied to the shelter by means of an external fan at the rate of three cfm per occupant. The ventilation air was pre-conditioned to follow a cycle typical of that to be expected during a mid-summer day at Gainesville, Florida, as shown by Figure 22.

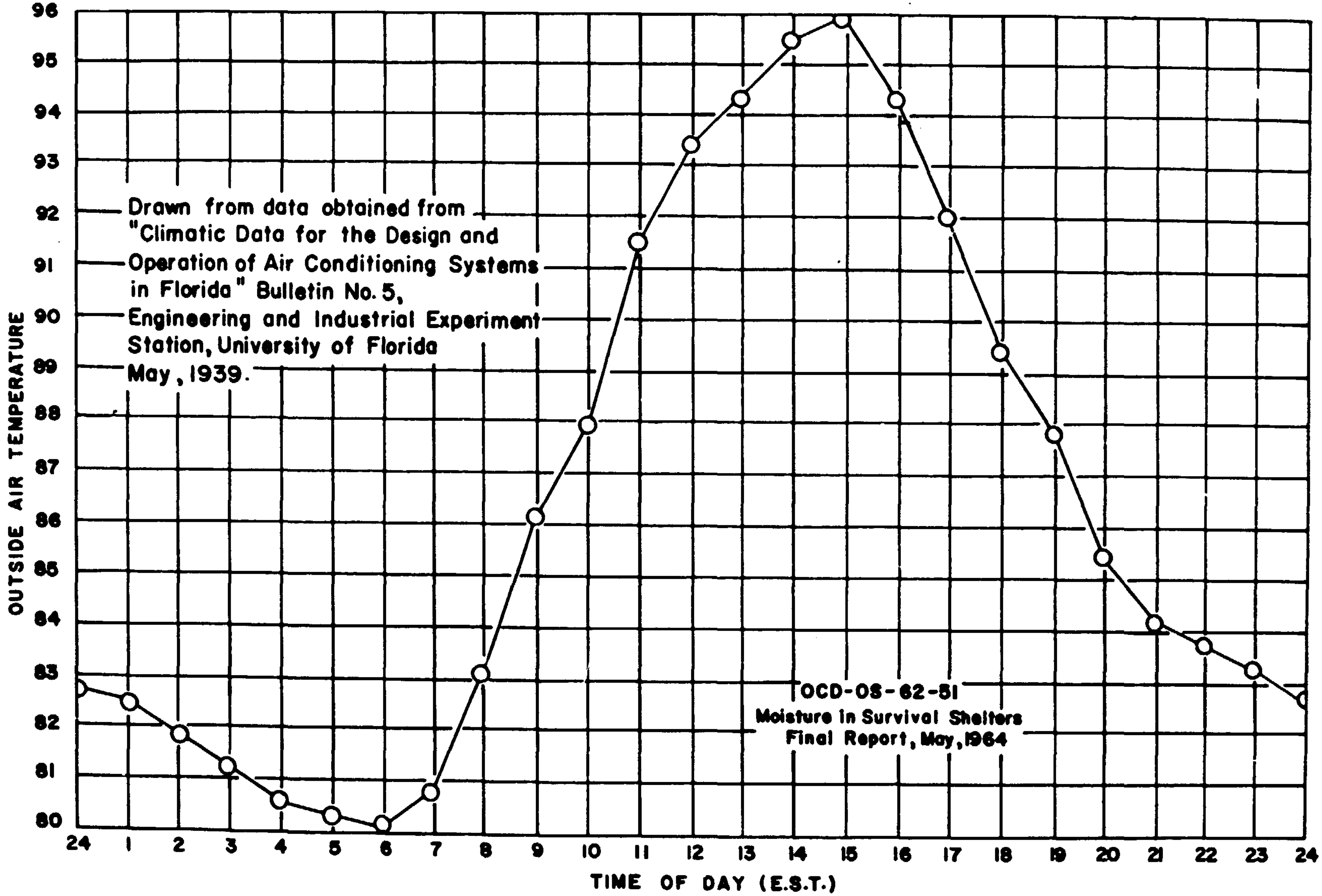

Fig. 22 Temperature Variation with Time for a Typical Summer Day
Gainesville, Florida

At the start of the test employing the water coil, the shelter dry bulb temperature was 81 F, the effective temperature was 79 and the relative humidity 87 per cent. Well water entered the coil at 71.50 F, left at 74.86 F, and flowed at the rate of 1915 pounds per hour. The water absorbed 6440 Btu per hour, while the heat release of the twelve occupants was 4800 Btu per hour. At the end of forty-eight hours, conditions in the shelter appeared to have stabilized at 79 F dry bulb, 77.5 F effective temperature, and 88 per cent relative humidity. During this period, 76.6 pounds of condensate were collected from the coil, which represented 73 per cent of the water evaporated by the simulated occupants.

Results of the test are depicted in graphical form in Figure 19 and it appears that considerable success was achieved in securing environmental control utilizing ground water at 71.5 F, so that in regions where colder water may be anticipated, still better control may be envisioned. The results shown were achieved by the consumption of 5/12 horsepower, 1/3 horsepower for the pump and 1/12 horsepower for the fan.

If the period when the water coil was in use is contrasted with the period August 15-16, when the same ventilation rate was employed, but without the coil, the magnitude of its effect becomes apparent. Without the coil, the dry bulb temperature was eleven degrees higher at 90.5 F, the effective temperature was eleven degrees higher at 88.5 F, and the relative humidity four per cent higher at 92%.

Figure 19 also illustrates the increase in temperature and relative humidity which occurred when the use of the water coil was discontinued even though the ventilation rate was increased from three to ten cfm per occupant.

Since the results achieved with the previously described water coil were successful, it was decided to conduct another test using a larger water coil, a larger fan, and a greater amount of ground water in a larger shelter. The structure selected for this test was a partially buried 100 occupant shelter, built with poured concrete floor, concrete block walls, and a roof made of prestressed concrete beams (See Figure 3). A water coil was used which had a width of thirty-five inches, a height of eighteen inches, a depth of nine inches and a copper coil of 5/8 inch tubing, six rows deep. The coil had a face area of 4.25 square feet and an exit air velocity of 330 feet per minute.

Water was delivered to the coil by a 1/2 horsepower submerged pump, in a well of 75 feet depth. The water level in the well during sustained pumping was not determined. Water entered the coil at 72.2 F and left at 75.65 F, at a flow rate of 6000 pounds per hour. The water absorbed 20,700 Btu per hour which was 51.6 per cent of the total energy released in the shelter by the simulated occupants. The amount of condensate from the coil was not determined.

Figure 23 is a plot of dry bulb temperature, effective temperature, and relative humidity for the period that the water coil was in operation. During this forty-eight hour period, the dry bulb temperature rose from an initial value of 82 F to 87 F and the effective temperature increased two degrees, to 84 F. The relative humidity decreased about five per cent. Figure 23 supports the conclusion that the coil was undersized for the load imposed upon it. However, when the 3.45 Btu per pound of water absorbed in the second test is compared with the 3.36 Btu per pound found for the first test, the efficiency of the two coils is seen to be substantially the same.

Further comparison of the two tests seems to indicate that as the size of the coil, water pump, and fan increases, the horsepower does not rise proportionately. In the first water coil test, a cooling effect of 6440 Btu per hour required an input of 0.42 horsepower. In the second test, a cooling effect of 20,700 Btu per hour was obtained with an expenditure of 0.83 horsepower. Thus, there was an improvement from 15,400 Btu per horsepower hour in the first test to 25,000 Btu per horsepower hour in the second test.

In order to handle the entire heat release of the 100 occupants, it would have been necessary to double the capacity of the cold water coil. Had this been done by installing another unit of similar size and configuration then the environment in the shelter could have been controlled with a power expenditure of about 1.7 horsepower. In order to achieve the same rate of heat removal utilizing an electrically driven, compression refrigeration, air conditioning system, a minimum of 3 1/2 horsepower would have been required to drive the compressor alone. In addition, motors of 1/3 and 1/2 horsepower respectively, would have been required to circulate air across the evaporator and condensor coils. The compression refrigeration system would thus consume about 4.3 horsepower compared to 1.7 horsepower for the water coil system.

A further advantage of the system employing ground water is its relative simplicity compared to mechanical refrigeration. The possibility of maintaining such a system with unskilled labor appears much greater than for conventional air conditioning equipment.

In summary, it appears that the use of ground water circulating through a coil where it absorbs heat from the shelter air offers an economical method of ameliorating shelter environments. Since this system proved feasible in Gainesville, Florida, with its high ground water temperature of 72 F, it appears that it could also be used with success throughout almost the entire United States. The ventilation air temperatures characteristic of summer conditions do not vary widely with location, while the ground water temperatures become lower as one proceeds north and west, so that the driving force for heat transfer from shelter

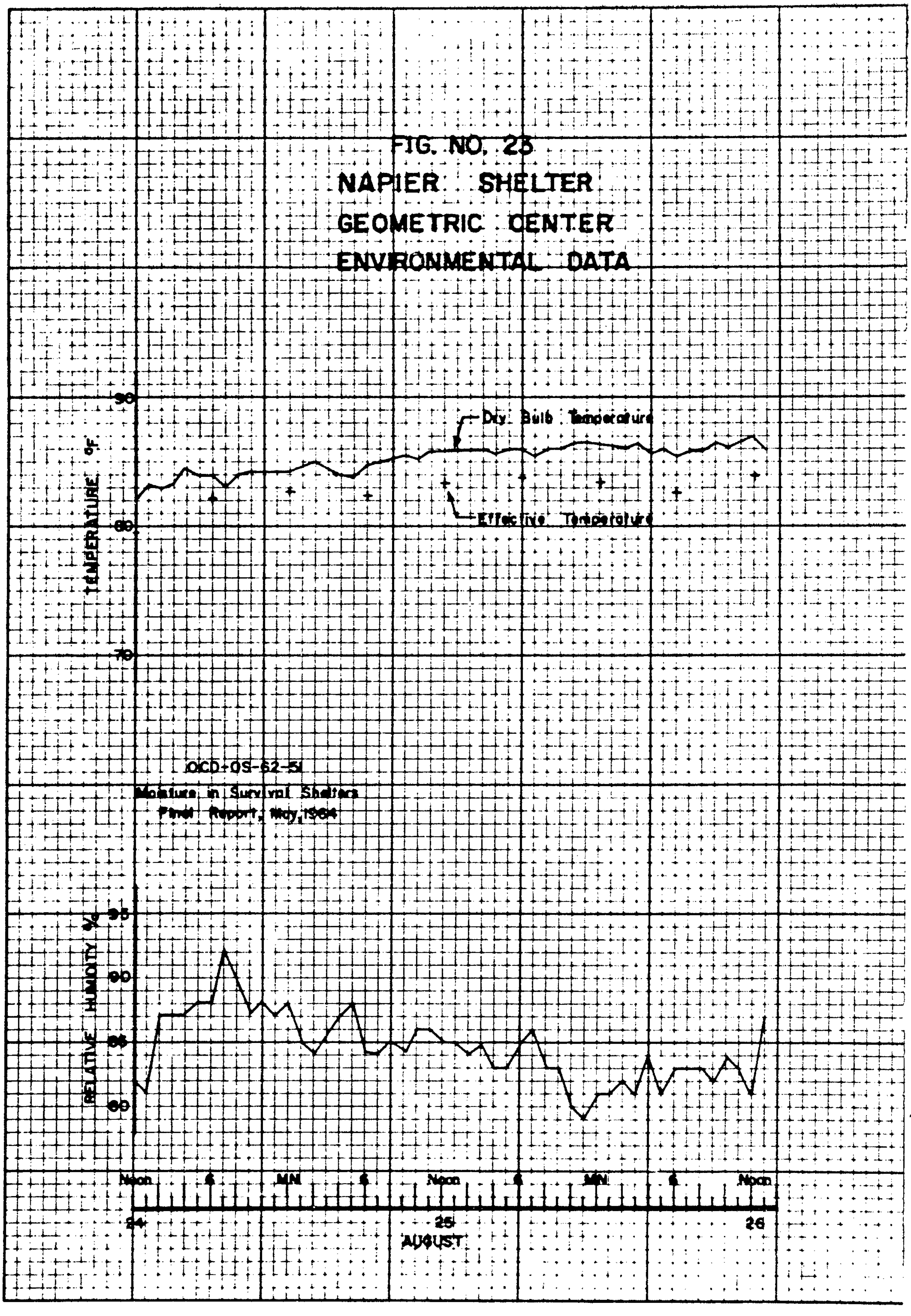

FIG. NO. 23
NAPIER SHELTER
GEOMETRIC CENTER
ENVIRONMENTAL DATA

air to water coil may be assumed to increase, thereby improving the operation of this type of system over that already demonstrated.

It must be pointed out that such a system is dependent on the availability of ground water. In Florida, it is possible to obtain adequate water from wells ranging in depth from 60 to 80 feet, and in such wells, the water level will usually rise to within thirty feet of the surface. This materially reduces the pump horsepower when a comparison of the availability of water in the state of Florida is made with other sections of the country that require water wells to a depth of 150 to 200 feet. Thus, even though cold ground water is available, consideration must be given to the amount of power that goes into delivering this water to a point within the shelter where it can be passed through a water coil.

Air Conditioning Systems as a Means of Controlling Shelter Environment. No actual test installations were made where refrigeration equipment was used as a means of environmental control. Conditioning the shelter environment by such a system would require installation of a direct expansion coil and fan within the shelter and location of the compressor and condenser outside of the shelter. Thus, heat removed from the shelter air or heat removed as a result of condensing moisture from the air, would be transferred to the condenser and would be dissipated to air outside of the shelter. The availability and performance of commercial refrigeration has been established and documented by consulting engineers and by manufacturers of air conditioning equipment. Thus, if the loads that such a system is to carry can be established, it is possible to select standard equipment to meet a known load. Since the tests which have been previously described covering heat removal by means of ground water and water coils established load values, it would be possible on the basis of these values to select mechanical air conditioning systems suitable for handling these loads. Two factors go into a selection of air conditioning equipment; first, the internal load within the space to be conditioned, and second, the external load which will transfer heat into the conditioned space.

Under actual occupancy conditions in a survival shelter it may be assumed that the major portion of the internal load will be generated by the metabolic heat released by the occupants in the shelter. As previously stated, experience and tests have indicated that a total heat release of 400 Btu per hour per occupant may be expected. This heat will be released in the shelter in two forms, sensible heat, and latent heat. The exact ratio of these forms is dependent on the ambient temperature of the shelter. On this basis, internal loads within a shelter can be calculated by multiplying the number of occupants times the heat release rate of the individual occupant. The external load is a function of ground temperature in the locality of the shelter. In regions north of a line drawn through the Georgia-Florida border, the ground temperature even during the summer months, is in most cases equal to or lower than the desired dry bulb temperature within the shelter. Therefore, for shelters which are located entirely below ground and in sections of the United States north of the Georgia-Florida border, the internal load and conditioning of the ventilation air would constitute the entire load on an air conditioning system during the summer months. For shelters located in northern sections of the country, it is possible that a good portion of the internal load can be absorbed by the surrounding earth, because available data indicate that earth temperatures in these localities are well below the desired ambient temperature within the shelter. In sections of the country where high earth temperatures are encountered, mainly certain sections of Texas, Mississippi, Louisiana and Florida, it is possible that additional air conditioning equipment might be needed to handle external loads.

In the absence of definite information with regard to climatic conditions and ground temperatures, a good rule of thumb for estimating loads would be one ton of air conditioning capacity for each twenty occupants to be housed in a shelter. In most climates one ton of air conditioning can be produced by a compressor driven by a one horsepower electric motor. When the efficiency of an electric motor is taken into account, the net electrical input is usually estimated as one kilowatt hour input per horsepower hour of compressor operation. Thus, a shelter located in northern Florida designed for twenty occupants could be air conditioned with a one ton unit (heat removal capacity of 12,000 Btu per hour) driven by a one horsepower electric motor with an electrical input of one kilowatt hour or 3,413 Btu per hour energy input. Since the internal load in such a shelter would be (20) (400) or 8000 Btu per hour, 4000 Btu per hour would be available for external loads, cooling of ventilation air and additional internal loads such as lighting, circulating fan motor and cooking. Depending upon the means of condensing the hot refrigerant, a 1/4 horsepower motor would be needed to operate a condenser fan or to operate a water pump for a water condenser. Approximately a 1/6 horsepower fan would be needed to circulate air across the cooling coil.

In climates where heat might be needed during winter months in shelters, reverse cycle refrigeration could be used as a means of heating shelter air. This would necessitate control equipment on the air conditioning system which would reverse the function of the evaporator and condenser. During the winter months when heat is needed in the shelter, refrigerant would be evaporated in a heat exchanger located outside of the shelter and would result in lowering of outside air temperatures. The heat absorbed by the refrigerant would be transferred to the condenser which would be located inside of the shelter space. Thus, by proper control, one piece of equipment could be used for heating in the winter and cooling in the summer. Commercial units in the one ton range are available but in most cases are integral units and in many cases have a single motor operating the condenser and evaporator fan. Such units are available for approximately $200.00 for straight cooling and $225.00 with controls for reversing the cycle for heating. If there were a demand for split units in this size and this demand were sufficient to warrant mass production, such units could probably be produced for approximately $275.00 for straight cooling and $300.00 for reverse cycle operation.

V. POWER REQUIREMENTS FOR ENVIRONMENTAL CONTROL

Power Sources. All of the methods for environmental control in survival shelters which were found satisfactory and which have been previously described in this report required a source of power for operation. Three sources of power were considered.

1. Existing utility service.

2. Hand power furnished by shelter occupants.

3. An auxiliary power system such as storage batteries or internal combustion engines.

Public utility power plants and their associated distribution systems are vulnerable to nuclear attack and even if a power system survived the blast effect of such an attack, the problems of protection for operating and maintenance personnel in such a system would be almost insurmountable. Assuming that generating stations could be made safe from the radiation effects of fallout, there would still exist the problem of keeping the electrical distribution system in operation under conditions where service crews could not go out and make repairs. Since there are many operations in distribution systems that cannot be handled by remote control and since under fallout conditions personnel conducting such operations would be subjected to extreme radiation hazards, there would appear to be no immediate solution which would assure a continuous flow of electrical energy throughout a utility system's distribution lines. Therefore, it was assumed that existing power from public utilities could not be counted on to meet the needs of protective shelters under conditions which would follow an all out nuclear attack.

The possibility of utilizing the power that could be produced by muscular action of the occupants of a shelter was considered and an investigation was made with respect to the known ability of human beings to produce power. Reports of numerous tests and experiments were found, documenting the abilities of human beings with respect to energy production. Typical of these are tests which were conducted by the American Society of Heating and Ventilating Engineers (Transactions ASHVE, Vol. 37, p. 541) indicating that a healthy male adult can produce approximately one-tenth horsepower for a period of two hours. This output was obtained by using shoulder and arm muscles and lifting a weight by means of a rope passing over a single pulley. Another test of a similar nature, made in Stockholm, Sweden, in 1948 ("Determination of Physical Working Capacity," Holgen, Wahlund, Suppl. 215, Acta Medica Scandinavica, Stockholm, 1948) using young male athletes producing power by means of leg muscles operating a bicycle connected to a dynamometer, indicated that such individuals can produce two-tenths of a horsepower for twenty minutes. At the end of such a period,

the subjects who performed these tests were exhausted. On the basis of the previously described tests and other literature it was considered safe to assume that an average adult male in good physical condition might be depended on for one-tenth horsepower for a period up to two hours and that by proper scheduling as much as one-tenth horsepower per such an occupant of a survival shelter might be available for as much as eight hours per day.

A limited test program was conducted to determine if hand driven fans that were available and being sold for shelter installation would meet the ventilation requirements of fallout shelter occupants and if such fans could be operated over expected periods of occupancy by persons within the shelter. The results of these tests are shown in Figures Number 24, 25, and 26. A review of these test results indicates that all of the fans tested would supply sufficient air for ventilation purposes with horsepower inputs well within the capabilities of human beings. In all cases, the horsepower input to each of the fans tested was in excess of the theoretical horsepower required to move a cubic foot of air against a pressure of one inch of water. Actual fan efficiencies were found to be about 40%. Thus it would appear that an investigation into the development of a more efficient ventilating fan might be in order.

Consideration of auxiliary power systems was limited to such systems as were commercially available and no attempt was made to investigate systems which might require a development or research effort. Such systems would have included nuclear and solar power, fuel cells and new types of storage batteries.

Conventional storage batteries were considered and were ruled out, except as a means for starting auxiliary power plants and as a source of emergency power for shelter lights and communication equipment. Their first cost is high, there is need for auxiliary equipment to keep the batteries charged, they occupy a considerable amount of space and most commercial batteries have acids as a working fluid and produce explosive fumes during the recharging process.

Internal combustion engines were considered as direct drives for environmental control equipment. However, since a source of lighting would also be needed in survival shelters, it was decided that internal combustion engines used to drive electric generators would meet the power requirements of a survival shelter in all respects, and that the gain in efficiency of direct drives over electrical generators would not be worth the inconvenience that the direct drive system would bring about. Therefore, it was decided to investigate internal combustion engines coupled to electrical generators.

Internal combustion engines are available for use with a wide variation of fuels. For the purpose of this report, consideration was given to internal combustion engines which utilized gasoline, liquefied petroleum gas and low volatile fuel oils.

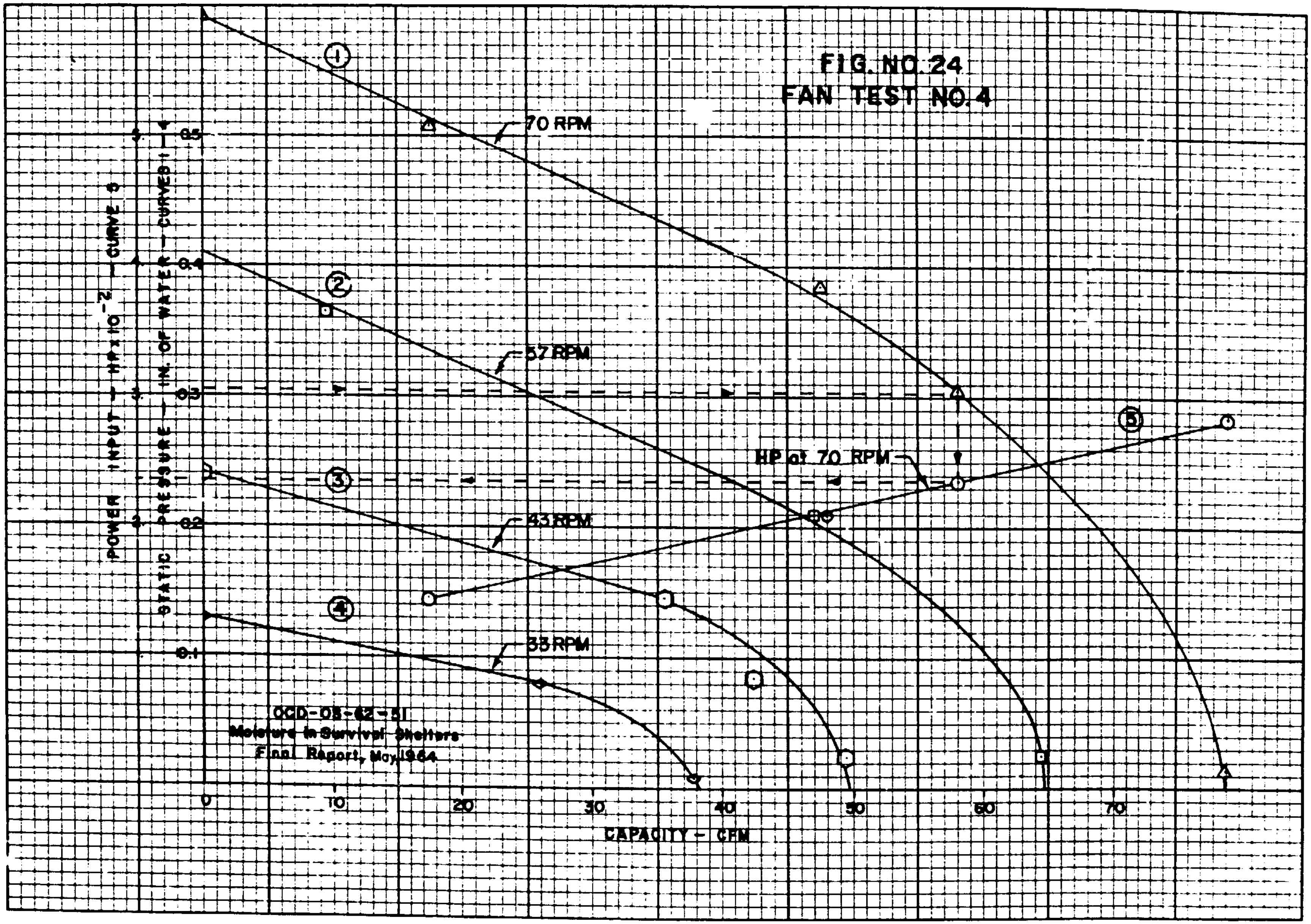

FIG. NO. 24
FAN TEST NO. 4
70 RPM
57 RPM
43 RPM
33 RPM
HP at 70 RPM
1
2
3
4
5
POWER INPUT — HP x 10^-2 — CURVE 5
STATIC PRESSURE — IN. OF WATER — CURVES 1 - 4
0.1
0.2
0.3
0.4
0.5
2
3
4
5
0
10
20
30
40
50
60
70
CAPACITY — CFM
OCD-OS-62-51
Moisture in Survival Shelters
Final Report, May 1964

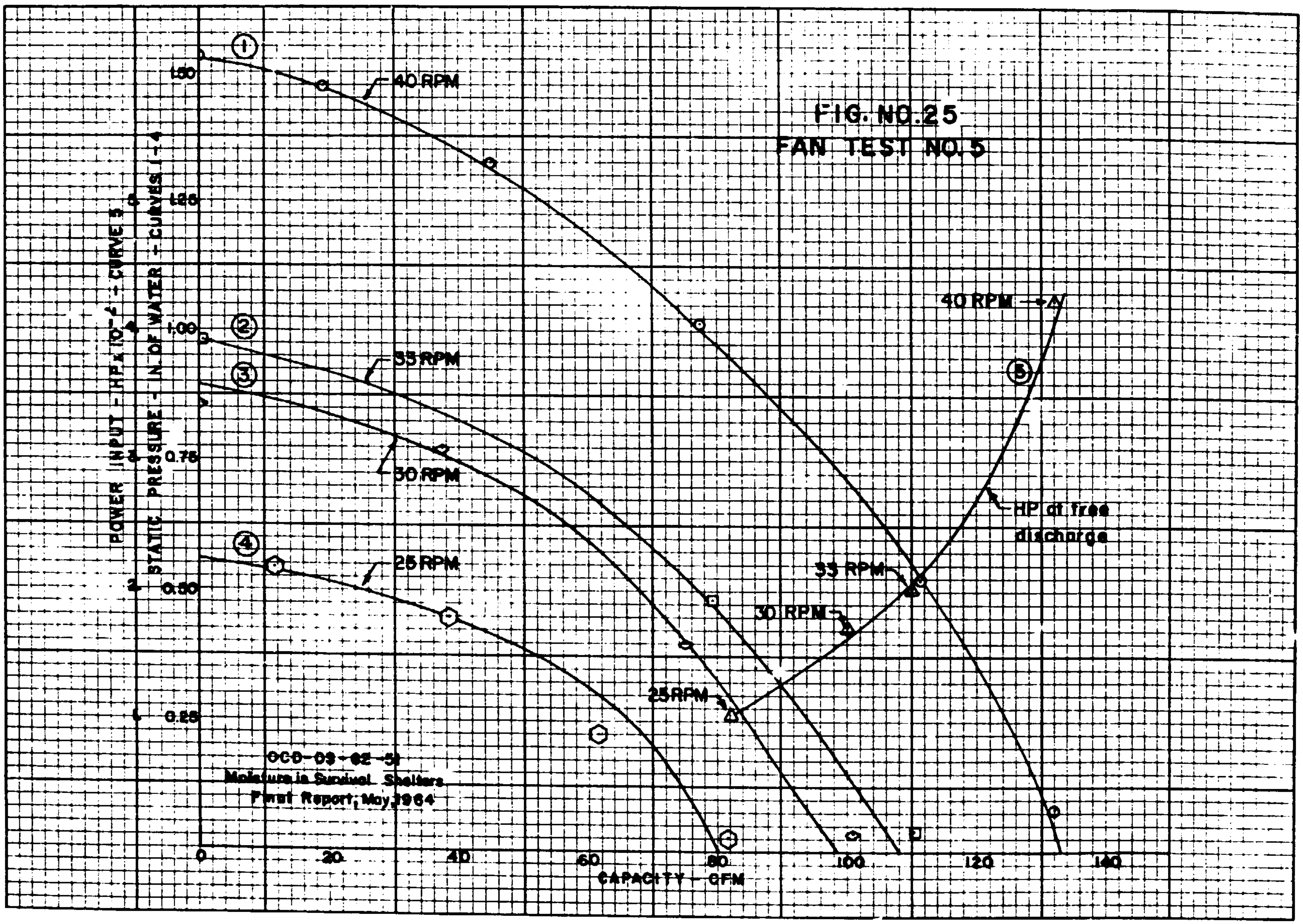

FIG. NO. 25
FAN TEST NO. 5
40 RPM
35 RPM
30 RPM
25 RPM
40 RPM
35 RPM
30 RPM
25 RPM
HP at free discharge
1
2
3
4
5
POWER INPUT - HP x 10^-2 - CURVE 5
STATIC PRESSURE - IN. OF WATER - CURVES 1-4
1.50
1.25
1.00
0.75
0.50
0.25
5
4
3
2
1
0
20
40
60
80
100
120
140
CAPACITY - CFM
OCD-OS-62-51
Moisture in Survival Shelters
Final Report, May 1964

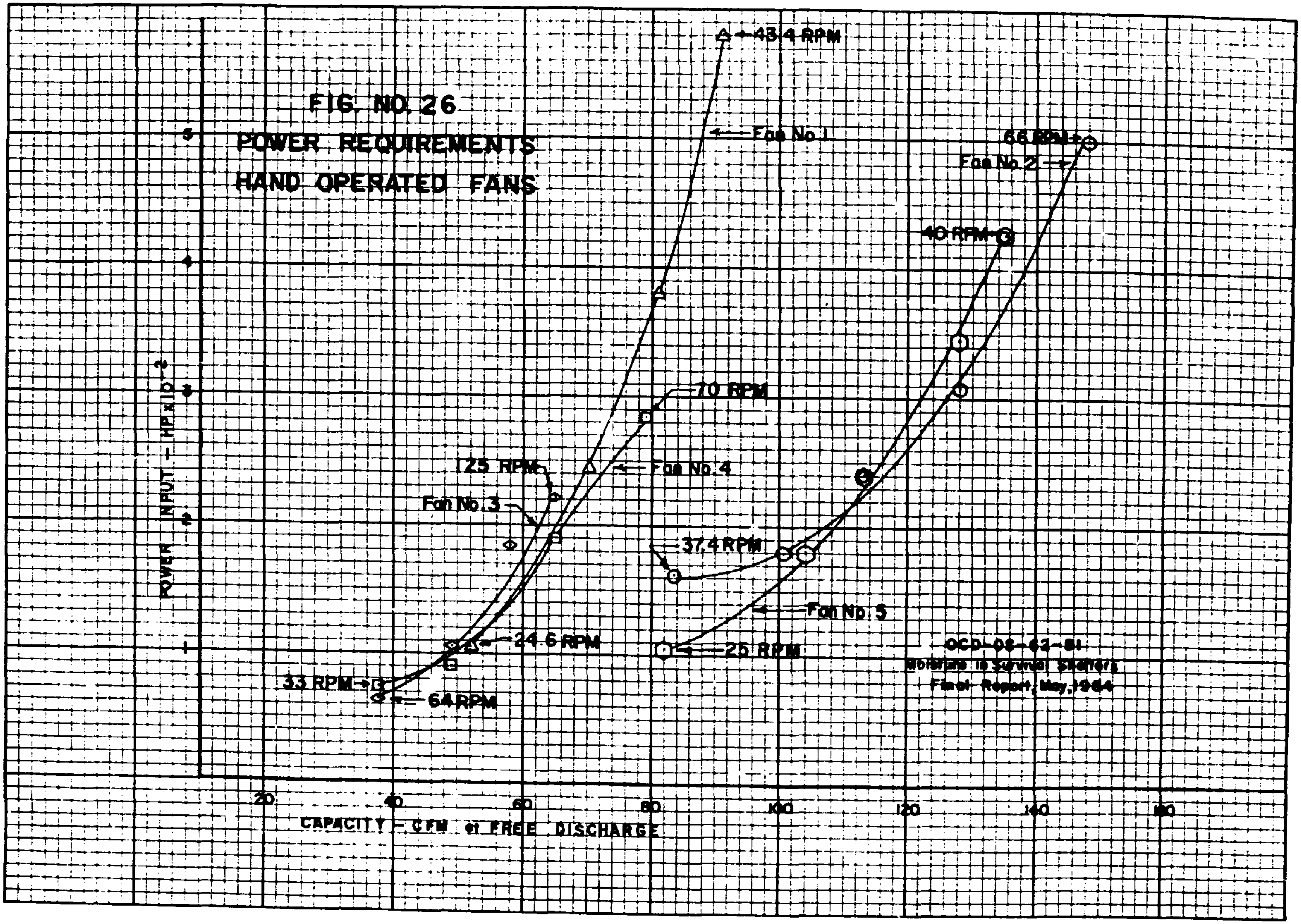

FIG. NO. 26
POWER REQUIREMENTS
HAND OPERATED FANS
43.4 RPM
Fan No. 1
66 RPM
Fan No. 2
40 RPM
70 RPM
125 RPM
Fan No. 4
Fan No. 3
37.4 RPM
Fan No. 5
24.6 RPM
25 RPM
33 RPM
64 RPM
OCD-OS-62-81
Moisture in Survival Shelters
Final Report, May, 1964
POWER INPUT - HP x 10⁻²
CAPACITY - CFM at FREE DISCHARGE
1
2
3
4
5
20
40
60
80
100
120
140
160

These particular fuels are available and reasonably priced in all sections of the United States. An engine powered by any of the above fuels could be used to drive an electric generator. Engines were evaluated with respect to availability, reliability, safety, first cost, and operating cost. All of the types listed above were found to be commercially available in "package" units. That is, a single unit could be purchased driven by either a gasoline, liquefied petroleum gas or Diesel engine which would produce electrical power and have starting gear and controls as standard equipment. All of these units were found to be available with either water cooled or air cooled engines. The choice between the use of an air cooled or water cooled engine would be dictated in some degree by the climatic conditions existing at the geographic location where unit operation was contemplated. Air cooled engines might not be satisfactory for desert operation and water cooled units might not be satisfactory in sections of the country where freezing weather might damage the engines during periods of standby. At least one commercially available air cooled diesel engine comes equipped with a centrifugal fan as an integral part of the engine flywheel and is equipped with an air duct for routing cooling air over the heated portion of the engine and exhausting the hot air out of the equipment room. A water cooled engine has one advantage over an air cooled engine. Waste heat from the water jacket could be utilized as a source of heat for the shelter in cold weather and as a source of hot water in all seasons. Of the types of prime movers investigated, that utilizing gasoline was found to be in the most plentiful supply, and available at the lowest first cost. A one kilowatt capacity unit producing electrical energy at 110 volts, 60 cycles and single phase could be obtained for approximately $200.00. The evaluation of such a unit with respect to reliability indicates that for intermittent operation and long periods of standby service that this unit leaves something to be desired.

The reliability of a gasoline powered unit is affected by two factors. When gasoline is used as a fuel and is stored for relatively long periods of time certain changes occur in the gasoline. These changes produce substances which will interfere with the moving parts, namely, the float control valve of the carburetor and such stationary parts as fuel jets within the carburetor. Since the need for operating such a plant might not occur for a period of years, some deterioration of the gasoline would almost certainly take place and such deterioration could cause malfunction at the very time that the unit was needed most. The second spot in a gasoline engine that would be vulnerable to deterioration after periods of inactivity would be the ignition system. Since a protective shelter may well be located in an area of high humidity, it is entirely likely that during standby periods, moisture could get into the coil, the condenser and the mechanism that controls the ignition system breaker points. Any such intrusion of moisture could bring about a failure in the starting sequence.

Thus, if gasoline drives are to be used, some procedure would need to be developed whereby the fuel supply could be replenished with fresh fuel and the ignition system be protected from moisture.

From a standpoint of safety, a gasoline fueled unit leaves much to be desired. A leak in a fuel line could release a volatile fuel into an area that probably would not be adequately ventilated. As the fuel volatilized an explosive mixture of air and vapor would be formed. This mixture would be heavier than air and would not be carried away by a natural chimney effect. Thus, on start up, an explosion and fire might occur. During operation, if a leak should occur, the results would be equally as bad.

For internal combustion engines operating with liquefied petroleum gas as a fuel, the availability of such units would be almost equal to the availability of gasoline driven units. In fact, a standard gasoline unit needs only a special carburetor to fit it for liquefied petroleum gas operation. Such an adaptor could be obtained for approximately $25.00, thus the first cost of this unit (of 1 kilowatt capacity) would be approximately 10% greater than the gasoline unit. Liquefied petroleum gas does not deteriorate with age, does not form any gummy substances and would thus correct some deficiencies in the reliability of the unit which prevail when gasoline is used as fuel. From the standpoint of safety, liquefied petroleum gas may be considered as more dangerous than gasoline. This fuel is stored under pressure, and at room temperatures and atmospheric pressure can exist only in vapor form. When this vapor mixes with air a combustible mixture heavier than air is produced. This fuel is contained in a pressure type system and if a leak develops would create a hazard from the standpoint of an explosion whether the unit is in operation or under standby conditions. The ignition system used by an engine operating with liquefied petroleum gas is the same as the ignition system in a gasoline engine and is, therefore, subject to the previously described deficiencies for gasoline engines.

Engines which operate on low volatile fuels commonly referred to as Diesel engines use a fuel that has a relatively high ignition point and which does not, under usual ambient temperatures, produce vapors to combine with air and form an explosive mixture. Furthermore, this type of engine does not have an electrical ignition system since ignition is achieved by means of building up high pressure in the engine's cylinders. Therefore, the Diesel engine is free of the moisture difficulties which might affect either the gasoline or liquefied petroleum gas engine. Diesel engines are not readily available in small sizes. There are perhaps two or three concerns which market a Diesel engine suitable for one and two kilowatt power plants, and it would take industry some time to meet the demands of a mass market in the Diesel engine field. At the present time, a one kilowatt auxiliary power unit

driven by a Diesel engine equipped with a centrifugal cooling fan would cost, approximately, $1000 or five times the cost of a similar gasoline unit. Operating costs of a Diesel are approximately 30% less than the gasoline or liquefied petroleum gas engine. This would result in a smaller fuel storage tank and since Diesel fuel does not deteriorate would remove one of the major causes of starting difficulties that are experienced in a gasoline engine. Of the three types of engines evaluated, the Diesel engine is superior from the standpoint of dependability, safety and operating cost. It is not as available as the other types of engines evaluated and from the standpoint of first cost is not competitive with these engines.

Ventilation Systems. Power requirements for moving air through a space such as a survival shelter are dependent on the resistance to air flow and the mechanical efficiency of the device used to move the air. Pressure differences with respect to air flow are usually small and in most cases related to pressure required to maintain a column of water which is usually measured in inches. A theoretical calculation is shown below which gives the horsepower required to move a cubic foot of air against a resistance of one inch of water, assuming that the fan is 100% efficient.

$$\text{h.p.} = \frac{(62.4\ \text{lb/ft}^3)(1\ \text{cfm})(1\ \text{in.})}{(12\ \text{in/ft})(33{,}000\ \text{ft lb/min})} = 0.0001573$$

The efficiency of a fan depends to a large extent on the shape of the fan blade, and upon the speed of the blade tip. In general, the best efficiency that can be expected from fans operating at designed speed, falls within the range of 70 to 80%. Unfortunately, this relatively high efficiency occurs when the fan is delivering from 40 to 60% of its maximum capacity, and if the capacity of the fan is increased by increasing the speed, the efficiency falls quite rapidly and for a forward curved blade operating at 80% capacity, an efficiency of 20% might be expected. When such fans are driven by electric motors and where a plentiful supply of electricity is available, it is only necessary to oversize a fan motor to increase air flow and the only penalty that is paid for this increased air flow is an increase in the electric bill. Therefore, it is not uncommon to find a major portion of the fans operating in commercial applications in an efficiency range from 15 to 20%. In the case of fans used for fallout shelter ventilation this practice should be re-evaluated if there is any thought of driving the ventilation fans with power developed by muscular activity of the occupants. In these cases fans should be selected and sized so that they will be operated at the maximum efficiency and thus conserve the energies of the occupants of the shelter. This would mean that in most cases the fan would operate in the range of 40 to 60% of its maximum air delivery capacity, but would probably operate between 70 and 80% efficiency. Assuming that a fan could be selected to operate at 70% efficiency the following calculations are made to cover the selection of a fan for a hundred occupant community shelter.

Additional assumptions are necessary and are as follows:

That 400 Btu per hour of heat are released per occupant and that 20 cfm per occupant is required to maintain environmental conditions at less than 85 F effective temperature.

That the distribution of people in such a shelter would be 25 adult males, 25 adult females and 50 children.

That such adult males could produce one-tenth of a horsepower for a two hour period.

That the static pressure the fan would need to overcome would be one inch of water.

$$h.p. = \frac{(2000\ ft^3/min)(0.000157\ h.p./cfm\ at\ 1\ in\ H_2O)}{(0.70\ fan\ eff.)}$$

$$h.p. = 0.448$$

Such a fan would need to be equipped with a mechanical drive that would be suitable for operation by the combined efforts of several people. The drive might take the form of a multiple bicycle drive unit and could possibly handle the efforts of five people simultaneously. Thus, if each adult male could be counted on to produce one-tenth of a horsepower for two hours out of each ten hour period, the needs of this shelter could be met. The above calculations seem to indicate that the horsepower required by the ventilating fan would fall within the capabilities of a group effort. However, it must be pointed out that when human beings are exerting themselves and producing work that their metabolic heat rate goes up and that the heat input to the shelter would be increased. It is possible that this increase due to activity might be offset by a corresponding decrease on the part of the individuals who were sleeping and therefore not exerting themselves. A further consideration that must be taken into account when thought is given to utilizing the efforts of the occupants is the possibility of illness which might disable a portion or all of the shelter occupants. Certainly, conditions within a fallout shelter are such that the possibility of an epidemic of respiratory ailments cannot be ignored and any interruption in the ventilation system would certainly aggravate the spread of and retard the recovery from respiratory diseases. Therefore, while it appears theoretically possible for occupants in a survival shelter to generate sufficient power for the operation of ventilation equipment, there is certainly little or no margin of safety in such an arrangement and it is felt that an auxiliary power system of some type should be installed to be used when and if the utility system fails and that perhaps human effort should be reserved to act as a standby or a reserve in the even that the auxiliary power system itself failed.

Ground Water Systems. The amount of power required to supply water to a coil and operate an auxiliary fan for any particular shelter will depend of the size and location of the shelter. Experiments and tests previously described in this report indicate that in central Florida one pound of water taken from a non-thermal well and brought into contact with shelter air can be expected to absorb approximately 3 1/2 Btu. Thus, assuming a metabolic rate of 400 Btu per hour per shelter occupant, 115 pounds of water per hour would be needed to remove the heat generated in a shelter by a single occupant. This is 13.85 gallons per hour or 0.231 gallons per minute. Using this quantity of water as typical and assuming a well with the water level 40 feet from the top of the ground during the time the pump was in operation and further assuming that the pressure drop or friction loss could be maintained at a value equivalent to 20 feet of water head and that the delivery head was negligible, then the total water horsepower per occupant would be:

$$\text{h.p.} = \frac{(115\ \text{lb/hr})(60\ \text{ft})}{(33{,}000\ \text{ft lb/min})(60\ \text{min/hr})} = 0.0035$$

Assuming that in small pumps the efficiency might be as low as 25% then the required horsepower would be in the order of 0.014 horsepower per occupant. Applying this value to the test in the Broyles shelter which had a twelve occupant capacity, a predicted horsepower requirement would be 0.169 horsepower. A test of this shelter was conducted and a one-third horsepower jet pump was used but no means was used to determine the energy left in the water as it was exhausted from the coil. It must be assumed that some energy was lost due to velocity head in the exhaust water, and therefore somewhat less than one-third horsepower was used in this installation.

Applying the same value of 0.014 horsepower per occupant to the Napier shelter, the predicted horsepower for the pump load would be 1.4 horsepower. When this value is compared to the actual test value it would appear that the pump supplying the water to the water coil in the Napier shelter was overloaded, since this pump was a half horsepower unit and was supplying water to a coil which handled 50% of the heat released by the 100 occupants in this shelter. Two possibilities exist. First, the one-half horsepower motor may have been overloaded and was actually producing seven-tenths of a horsepower. A second possibility is that the efficiency of this particular pump may have been greater than the 25% which was used to arrive at the horsepower requirement per occupant. However, the results of the two tests indicate that the horsepower requirements of a pump can be estimated with a great enough degree of accuracy to meet the needs of the shelter. Again it must be pointed out that the use of such a water coil would be more effective in an area where cooler water is available.

The following is a theoretical study to determine the possibility of utilizing the muscular effort of shelter occupants to pump sufficient water through a coil and pipe system and to operate a circulating fan to move shelter air across such a coil. It may be assumed that the efforts of the occupants could be applied to a positive displacement type of pump and that such a pump would have an efficiency of the order of 50%. This would reduce the horsepower requirement for a 100 occupant shelter (the size of the Napier shelter) to 0.70 horsepower, a value that previous experiments indicate could be met by a group of people if their energies were properly connected to a pump by some mechanical device, such as a system of levers or a bicycle drive. In conjunction with the pump, a fan would be necessary to circulate the ventilating air across the coil and to supply additional air from outside which would be required to meet the oxygen demands of the occupants and prevent build-up in carbon dioxide within the shelter.

Since the quantity of purely metabolic air that is needed is relatively small (approximately 3 cfm per occupant) and the resistance to air flow that would be offered by a cooling coil can, in most instances, be limited to 1/4 inch of water head, the horsepower required to bring in fresh air and circulate shelter air would be small when compared to the power requirements needed to supply water to a coil. The use of a ground water system operated by muscular activity of the shelter occupants would require a slightly greater expenditure of energy than the energy required to operate a ventilating fan. However, the effort for the ground water system would still be within the estimated capabilities of a group of human beings. In the case of the ground water system, there is an even smaller margin of safety, and it is recommended that if the use of the ground water system is contemplated that this system be powered by an independent auxiliary power system and once again that manual effort be used as a reserve to back up and protect against the possible failure of the auxiliary power system.

Air Conditioning Systems. No tests were conducted utilizing conventional compression refrigeration equipment. Such systems, based on the condensation of compressed refrigerant vapor and the subsequent evaporation of the liquid phase to cause a refrigerating effect, have been in use for many years and performance characteristics are well known. In general, an electrical motor consuming one kilowatt of power will deliver one shaft horsepower to a refrigeration compressor which, in turn, will produce one ton of refrigeration (12,000 Btu per hour heat removal). In addition, fractional horsepower motors are needed to power the fan which circulates the air to be conditioned across the evaporator coil, and to power a water pump or a fan to cool the condenser. In the aggregate, about one and one-third shaft horsepower input are required per ton of refrigeration. It must be pointed out that the horsepower requirements for any refrigeration system are related to the climatic conditions in the locality where the refrigeration or air conditioning system operates. Hot humid climates, where prevailing ground water temperatures are high, require more energy per ton of refrigeration than is needed in climates where climatic conditions are not extreme and relatively cool ground water is available. Thus, the figures cited above are valid for estimation purposes only and data available from manufacturers of air conditioning equipment should be consulted before a unit is selected.

On the basis of previously described tests with respect to man's ability to produce energy, it can be seen that even under the most favorable conditions, a man could not produce sufficient power to operate a compressor driven liquid-to-vapor air conditioning system, and this particular air conditioning system was chosen since of all the vapor-to-liquid systems, the one containing a compressor is the most efficient. A compressor driven liquid-to-vapor cycle has a coefficient of performance (the ratio of refrigeration effect produced to energy input to the system) of approximately 3.5, while an absorption system which uses a high temperature gas as a driving force has a coefficient of performance of 1. Thus, if man would not be capable of furnishing power for a compressor system, he would not be capable of furnishing power for any of the other commercially available cycles. Some consideration was given to direct drives from internal combustion engines to refrigeration compressors and it can be shown that such a system would operate more efficiently since the electrical losses in the generator and the driving motor for the compressor would be eliminated. However, the controls for such a system are more complicated and more expensive than the control for a conventional electrically operated air conditioning system and since there will be a need for electric lights in a shelter, an electric generator driven by an internal combustion engine and supplying electricity for lights and air conditioning operation was considered the most practical unit.

VI. CONCLUSIONS

To appreciate the significance of moisture in survival shelters, a discussion of the effect that moisture has on the well-being of shelter occupants is in order. The human body, in common with other heat engines, consumes fuel to produce heat, in order to maintain the body at an even temperature. Three mechanisms, convection and radiation of thermal energy, and the vaporization of body moisture are available to effect net energy interchange with the surroundings. The direction must always be towards a region of lower potential, i.e., radiation and convection to surroundings of lower temperature, or evaporation of moisture into a surrounding atmosphere which is not yet saturated with water vapor. The body can, within limits, adjust its heat rejection mechanisms to suit the situation, thus in desert climates with temperatures above those of the body, temperature regulation is achieved by copious sweating. In regions of high humidity but cool air, the body loses heat by radiation and conduction. When both high temperature and high humidity conditions exist, the body is unable to get rid of the necessary heat and body temperature begins to rise. If this condition persists, disability or death results, depending on the degree of temperature elevation and its duration.

A measure of the interrelated effects of temperature and humidity is the so-called effective temperature. Air velocity is also considered and given some weight in determining the effective temperature but, at the ventilation rates expected in survival shelters, is of little significance. Experiments conducted by the American Society of Heating and Ventilating Engineers (Transactions, ASHVE, Vol. 30, 1924) and others ("Temperature and Human Life," Princeton University Press, 1949, C.E.A. Winslow and L. P. Herrington and ASME Paper 59-AV-12, 1959, S. H. Dole) indicate that 85 F is the maximum effective temperature which human beings can tolerate for extended periods without damaging effects.

The largest and most troublesome sources of moisture in survival shelters are the occupants of such shelters.

Leakage of moisture into survival shelters in the form of seepage or vapor infiltration constitutes a real problem with respect to humidity and is one that should be planned for and taken care of during the construction of a shelter. Efforts to stop leakage and infiltration in existing shelters met with only limited success. None of the materials used to stop leakage and infiltration were completely successful. All were considered to be somewhat difficult to apply and all were more expensive than the type of paint which is normally used for decorative purposes. Under extreme conditions, in a shelter designed for twelve people, moisture migration can account for a latent heat load equivalent to one and one-half occupants. Moisture which seeps into the

shelter and wets the shelter walls, ceiling or floor has an effect which varies with the shelter environment, but was evaluated as equivalent to one additional occupant for each 262 to 378 square feet of wetted surface as a result of tests conducted in a 100 person semi-buried shelter.

Wetted surfaces within a shelter are not in every case detrimental to the shelter environment. Under conditions where the air adjacent to a wetted surface is warmer than the surface, and is not saturated with water vapor, an advantageous mass and energy transfer may take place. When moisture is evaporated into the shelter ventilation air as a result of heat transfer from within the shelter envelope, the effective temperature of the shelter environment is lowered and the shelter made more habitable thereby. The limit of such advantageous evaporation is reached, when the moisture thus added to the air, plus that acquired from the metabolism of the occupants, causes the exhaust from the shelter to leave saturated with water vapor.

Moisture in the ventilation air will vary with respect to geographic location and will constitute a greater problem with respect to shelter environment in hot humid climates. If the absolute humidity of the ventilating air is high, the amount of moisture that such air can remove from the shelter is limited. This problem can be overcome by supplying sufficient ventilation air so that all of the moisture generated within a shelter can be absorbed and removed from the shelter. If the ventilation rate is somewhat in excess of that needed for moisture removal then dry bulb conditions within the shelter can be favorably affected. Tests conducted and explained more fully in the body of this report indicate that twenty cubic feet of ventilation air per minute per shelter occupant will be sufficient to maintain habitable conditions in a survival shelter during a typical summer period at latitude 30° North.

It was found by means of theoretical calculations and by actual tests that chemical absorbents, mechanical dehumidifiers, wall liners, storage of moisture in shelter structures, or any integrally contained device or system which would bring about a phase change from water vapor to liquid water would result in an increase in the effective temperature within the shelter. This occurs provided that the phase change takes place within the shelter and that means are not provided for removing the sensible heat accompanying such a change.

Water coils using ground water (temperature $^{\circ}$71.5 F) from non-thermal wells and equipped with circulating fans were tested and found to be an effective means of controlling environmental conditions within a shelter.

Theoretical studies were made with respect to mechanically driven refrigeration systems for use as air conditioning units.

It was found that there are available standard package units which are suitable for shelter conditioning if certain modifications are made. Such systems are the most complex of any environmental control systems studied and would require some knowledge of refrigeration principles if they were to be used and maintained under actual shelter operating conditions.

While it is theoretically possible that the human body could supply sufficient energy for the operation of blowers and pumps and thereby control environmental conditions in a shelter by means of air purging or conditioning with a water coil and fan arrangement, the margin of safety of such a power source is small and it is considered advisable to install an auxiliary power system for the operation of mechanical equipment.

Results of the investigation into internal combustion engines as a means for driving mechanical equipment indicate that greater flexibility is obtained if the engine is coupled to an electric generator and the electricity produced is used to operate mechanical components. Internal combustion engines operated on low volatile fuel and without an electrical ignition system (Diesel engines) were considered superior to gasoline or liquefied petroleum gas engines with respect to dependability, safety and operating costs but did not compare favorably with them with respect to first cost or availability in large numbers.

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A P P E N D I X

TABLE I
OCCURRENCE OF WATER LEAKAGE DURING SHELTER OCCUPANCY TESTS

me and Location of Shelter	Type Construction	Did Leakage Occur?	Type Leakage
Broyles: Gainesville, Florida	A	Yes	1
Summerlin: Gainesville, Florida	B	Yes	2
Napier: Gainesville, Florida	A	Yes	3
Central Stores: Gainesville, Florida	C	No	
Houston Motor Compound: Houston, Texas	C	No	
Prototype Community: Reading, Pa.	D	No	
Hershey: St. Louis, Missouri	E	Yes	4
Control Center: St. Louis, Missouri	E	No	
Abo School: Artesia, New Mexico	E	No	
Francis: Tucson, Arizona	E	Yes	5
Airport Utility Tunnel: Tucson, Arizona	F	Yes	6
Robert's Dairy (Cow): Elkhorn, Nebraska	D	Yes	7
Irvingdale Shelter: Lincoln, Nebraska	D	Yes	8
P.S.D.C. Expedient: Ft. Belvoir, Virginia	G	Yes	9
P.S.D.C. 200-Occupant: Ft. Belvoir, Va.	C	Yes	10
P.S.D.C. 1000-Occupant: Ft. Belvoir, Va.	C	No	
N.N.M.C. 100-Occupant: Bethesda, Maryland	H	Yes	11

TYPE OF CONSTRUCTION

pe	Description
-------------------------------	Semi-buired, concrete block
-------------------------------	Buried, steel tank
-------------------------------	Basement, reinforced concrete
-------------------------------	Semi-buried, reinforced concrete
-------------------------------	Buried, reinforced concrete
-------------------------------	Buried, corrugated steel culvert
-------------------------------	Above ground, earth filled walls
-------------------------------	Buried, corrugated steel arch

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pes of Leakage

Small leak in roof apparently due to crack in slab coupled with faulty water proofing.

Error in procedure in filling water supply tank, ruptured tank and shelter end wall.

Shelter leaked extensively. Roof membrane was inadequately lapped and may have torn due to shifting of earth cover. Hollow block walls partially filled up with water which then leaked into shelter at poorest mortar joints. Severe leakage at juncture of wall and floor slab.

TABLE I (Cont'd)

4. Due to a high water table, water rose into the shelter through a sump drain in the floor. By pumping 1 gallon per hour from the sump to keep the water level below floor level the floor was kept dry.

5. Above ground flood caused subsidence of poorly placed back fill, rupturing fill line to water tank. Water thus released below ground filled excavation and entered shelter around unsealed ventilation air inlet pipes.

6. Access manholes did not seal adequately and permitted entry of water during periods when water stood above tunnel after heavy rains.

7. Due to an overloading of earth on the shelter roof the supporting concrete cracked introducing a hole for the leakage of water. The excess of earth was removed, however, the hole remains and a patch should be made to prevent water leakage.

8. The elevation of the shelter entrance was below that of the area surrounding the shelter. Before an earth barrier was moved in front of the entrance, ground water from heavy rains ran into the shelter through the entrance. The earth barrier kept the shelter dry.

9. Water leaked through the layers of asphalt roofing paper buried 3 inches under the surface. Using a 4 mil continuous plastic membrane which replaced the roofing paper prevented leakage.

10. Toilet in basement overflowed due to stoppage or inadequate outfall to drain field. Actual cause not definitely ascertained.

11. Rainwater entered juncture of auxiliary access ramp and equipment room after draining along incomplete back filling.

Table II. Moisture Contribution to Ventilation Air By Wetted Floor.

Time	Temperature, Degrees Fahrenheit									Specific Humidity lbs water/lb dry air		
	Inlets				Outlet		Geometric Center		On Floor			
	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb	Dry Bulb	In	Out	Diff.
0900	102	94.0	102.5	-	95.0	86.5	87.0	86.5	89.5	0.0335	0.0257	-
0906	102	94.0	103.0	-	95.0	86.5	86.0	86.0	89.5	0.0335	0.0257	-
0918	86.0	83.0	86.5	-	92.0	85.0	92.0	85.5	87.5	0.0239	0.0248	0.0009
0924	89.5	85.5	89.5	-	92.0	85.0	93.0	86.0	87.5	0.0260	0.0248	-
0930 *	89.2	78.5	90.0	78.8	92.0	85.1	92.2	85.1	-	0.0186	0.0250	0.0064
0940	90.0	79.5	90.0	79.5	91.5	84.5	91.5	85.0	86.0	0.0195	0.0242	0.0047
1002	92.0	-	91.5	84.0	91.0	84.5	92.0	85.0	86.5	0.0238	0.0242	0.0004
1020 *	89.5	77.5	94.0	79.0	91.0	83.0	90.5	83.5	-	0.0176	0.0238	0.0062
1031	87.5	79.0	88.0	-	90.5	84.0	91.0	84.0	86.5	0.0193	0.0240	0.0047
1100	91.5	-	91.5	-	90.5	84.0	90.5	84.0	86.5	-	0.0240	-
1130	92.0	79.5	92.0	80.5	89.5	83.5	90.5	83.5	86.5	0.0190	0.0237	0.0047
1200	90.5	79.0	90.5	-	88.5	82.5	90.0	82.5	86.0	0.0188	0.0228	0.0040
1310	91.5	79.0	91.0	-	89.0	82.5	90.0	82.5	86.0	0.0185	0.0227	0.0042
1330	89.0	78.5	88.5	78.0	88.0	82.5	89.0	81.5	85.5	0.0185	0.0230	0.0045
1355	90.5	78.5	90.5	78.5	88.5	82.5	89.0	82.0	85.5	0.0182	[illegible]	[illegible]
1433	89.5	78.5	89.5	78.0	88.0	82.0	89.0	81.5	85.0	0.0183	0.0225	0.0042
1515		77.0	89.0	77.0	[illegible]	82.0	88.5	81.5	85.5	0.0173	0.0226	0.0053
1635	89.0	-	89.0	79.0	88.0	82.0	88.5	82.0	85.5	0.0192	0.0229	0.0037
1650 *	88.3	78.0	88.6	77.6	84.0	81.5	88.3	81.0	-	0.0181	0.0229	0.0048
					Average (Taken over period 1020 to 1650)					0.0184	0.0232	0.0048

* Denotes readings taken with hand psychrometer.
\- Denotes either no data or instruments not functioning properly.

Table III

Ambient Conditions and Moisture Removal During Dehumidification Test.
Broyles Shelter - February 25, 1962 - May 17, 1962

Date	Thermocouple Number 8	10	14 *	R.H. % **	Moisture Removed liters per day
Feb.					
25	65.5	66.0	63.5	91	
26	66.0	67.0	63.5	91	
27	69.0	68.0	64.0	82	6.26
28	70.0	68.0	64.5	75	5.30
March					
1	71.0	68.5	65.0	62	4.44
2	71.5	69.0	65.0	57	4.14
3	71.5	69.0	65.0	52	3.60
4	71.0	67.5	65.5	50	3.19
5	70.5	64.5	65.0	49	3.00
6	70.0	63.0	64.5	46	2.71
7	69.0	61.0	64.5	45	2.36
8	68.5	59.5	64.0	44	2.26
9	68.0	59.5	64.0	46	2.27
10	67.5	60.0	63.5	46	2.36
11	68.0	61.5	63.0	47	2.33
12	69.0	64.0	63.5	48	2.64
13	69.5	66.5	63.5	50	2.71
14	69.5	65.5	63.5	46	2.50
15	70.0	65.0	63.5	46	2.32
16	69.5	63.5	63.5	46	2.28
17	69.0	63.5	63.5	45	2.13
18			63.0	43	2.02
19	68.5	61.0	63.0	43	1.89
20	68.0	63.0	63.0	43	1.97
21	68.0	62.5	63.0	43.5	1.97
22	69.0	63.0	63.0	45	2.00
23	69.0	63.5	63.0	45	2.16
24	69.0	63.5	63.0	45	2.10
25	69.0	63.5	63.0	45	2.30
26	69.5	64.0	63.5	45	2.16
27	69.5	64.5	63.5	44	2.07
28				47	
29	70.5	65.5	63.5	70	1.45
30	70.0	65.5	64.0	71	
31	69.5	66.5	64.0	72	

* Tc No. 8 measures dry bulb temperature at geometric center of shelter.
Tc No. 10 measures ground temperature immediately above ceiling.
Tc No. 14 measures undisturbed ground temperature at shelter floor level.

** R.H. signifies Relative Humidity

Table III (Cont.)

Ambient Conditions and Moisture Removal During Dehumidification Test.
Broyles Shelter - February 25, 1962 - May 17, 1962

Date	Thermocouple Number 8	10	14 *	R.H. % **	Moisture Removed liters per day
April					
1	69.5	67.0	64.0	73	0
2	71.5	68.0	65.0	73.5	0
3	79.0	67.5	65.0	33	3.98
4	79.0	67.0	65.0	27	3.92
5	73.0	67.0	65.0	22	4.06
6	70.5	68.5	65.0		
7	76.5	69.0	65.0	24	5.35
8	80.5	70.0	65.0	22	4.39
9	81.0	71.0	65.0	21	4.79
10	83.0	71.5	65.5	21	5.45
11	84.0	73.0	66.0	20	4.43
12	85.0	74.5	66.5	22	4.52
13	86.0	75.5	67.5	19	4.41
14	86.5	75.0	68.0	18	3.93
15	81.0	75.0	68.0	17	3.60
16	89.0	74.5	67.5	40	3.46
17	76.5	74.0	68.0	50	
18	82.5	71.5	67.5	31	
19	84.0	71.5	67.5	24	4.33
20	84.0	72.0	67.5	22	3.48
21	85.0	72.0	67.5	30	
22	86.5	72.0	67.5	38	
23	85.5	73.5	67.5	40	
24	86.5	74.0	68.0	30	5.82
25	86.5	75.0	68.5	23	6.65
26	86.5	78.5	69.0	25	3.83
27	87.0	76.0	69.0	23	5.03
28	88.0	77.0	69.5	22	4.26
29	88.0	78.5	70.0	20	3.88
30	89.5	79.5	70.0	20	3.62
May					
1	89.5	80.0	71.5	19	3.84
2	91.0	80.5	72.0	17.5	4.18
3	90.0	81.0	72.0	18	1.84
4	91.5	81.0	72.0	17	4.60
5	92.0	81.0	72.0	16	
6	91.5	81.0	72.5	16.5	3.37
7	92.0	79.5	72.5	16	3.21

* Tc No. 8 measures dry bulb temperature at geometric center of shelter.
Tc No. 10 measures ground temperature immediately above ceiling.
Tc No. 14 measures undisturbed ground temperature at shelter floor level.

** R.H. signifies Relative Humidity

Table III (Cont.)
Ambient Conditions and Moisture Removal During Dehumidification Test.
Broyles Shelter - February 25, 1962 - May 17, 1962

Date	Thermocouple Number 8	10	14 *	R.H. % **	Moisture Removed liters per day
May					
8	92.5	79.5	72.5	15.5	4.15
9	92.0	79.0	72.5	14.5	3.64
10	92.0	79.5	72.0	14	3.57
11	94.0	83.0	72.5	13	3.68
12	94.5	83.5	73.5	13	3.82
13	93.5	83.0	73.5	14	3.60
14	95.5	84.5	74.0	13	3.82
15	96.0	84.0	74.5	12.5	3.63
16	97.0	84.5	74.5	14	3.60
17	96.5	85.0	75.0	22***	3.92
18	96.5	85.0	75.0	24	3.92
19	96.5	85.0	75.0	27	3.85
20	97.0	85.0	75.5	27	3.78
21	97.0	85.0	75.5	27	4.38
22	97.5	86.0	75.5	27	3.78
23	98.0	86.5	76.0	27	3.80
24	98.0	87.0	76.0	26	3.73
25	98.5	87.5	76.0	26	3.72
26	99.0	88.0	76.5	22	3.27
27	100.0	88.5	76.5		
28	99.5	88.5	77.5	25	3.27
29	99.5	88.5	77.5	23	4.5
30	100.0	88.5	77.5	22	4.03
31	100.0	88.0	77.5	22	4.03

* Tc. No. 8 measures dry bulb temperature at geometric center of shelter.
Tc. No. 10 measures ground temperature immediately above ceiling.
Tc. No. 14 measures undisturbed ground temperature at shelter floor level.

** R.H. signifies Relative Humidity

*** Recording Hygrothermograph checked with sling psychrometer, found to be in error and recalibrated.

Table IV. Ambient Conditions and Moisture Removal During Dehumidification Test - Summerlin Shelter.

Date	Moisture Removal liters/24 hours	Relative Humidity % **	Dry Bulb Temp. °F **	Earth Temp. °F ***
1962				
March				
28	0.95	48	68.0	67.0
29	0.66	40	68.0	67.0
30	0.52	40	68.0	67.2
31	0.49	37	69.0	67.5
April				
1	0.50	36	70.0	68.0
2	0.40	41	70.0	68.0
3	0.35	33	70.0	69.0
4	0.29	34	70.0	69.0
5	0.37	34	70.0	69.0
6	0.39	34	70.0	69.0
7	0.36	34	70.0	69.0
8	0.30	34	71.0	70.0
9	0.32	33	71.0	70.0
10	0.33	32	71.0	70.0
11	0.30 *	35	72.0	71.5
12		34	72.0	71.5
13		34	72.0	71.5
14	0.20 *	32	72.5	71.5
15		32	73.0	71.5
16		30	73.0	71.5
17	0.15 *	30	73.0	72.0
18	0.13	30	73.0	72.0
19	0.19	31	73.0	72.2
20	0.26	31	74.0	72.5
21	0.24	31	74.0	72.8
22	0.22	31	75.0	73.0
23	0.20	31	74.0	73.0
24	0.23	31	75.0	73.0
25	0.30	31	75.0	74.0
26			76.0	
27		34	76.0	
28		34	76.0	
29		34	76.0	
30		32	77.0	

* Estimated rates based on total collection of water over period April 11, 1962, through April 17, 1962.

** Readings taken with Hygrothermograph located 5' from south wall, 2' from east wall, and 2.5' off floor

*** Thermocouple located 18" above geometric center of shelter ceiling.

Table V
Infiltration Test of Fallout Shelter

A. Broyles Shelter * See Figure 9		B. Summerlin Shelter ** See Figure 10	
Elapsed Time, Hours	Carbon Dioxide, Percent	Elapsed Time, Hours	Carbon Dioxide, Percent
0.57	12.60	0.00	7.6
0.72	13.00	0.58	8.2
0.92	12.20	3.23	8.3
3.27	7.70	3.57	8.1
3.47	7.15	4.15	8.1
3.67	6.70	5.90	8.1
4.30	5.60	7.95	8.2
4.43	5.80	8.00	8.0
4.60	5.40	20.73	8.0
5.00	5.10	20.90	7.8
5.25	4.90	23.23	7.0
6.25	4.40	24.50	7.4
6.43	4.20	25.23	7.4
7.03	3.50	28.35	7.0
7.30	3.40	46.60	6.0
7.50	3.50	46.74	5.9
7.67	3.20	49.18	5.8
		53.25	5.8

* Test started at 1100, April [illegible], [illegible].
** Test started at 1026, April 11, 1962.

Data for both tests taken with Hayes Orsat Analyzer.

Table No. VI Moisture Absorption by Chemically Treated Cellulose.

Treatment	① Sample number.	② Weight after exposure.	③ Weight after treating and drying (@ 105c).	④ Dry weight before treatment.	⑤ Water absorbed ②-③ gm or ②-④ gm.	⑥ Water absorbed by chemical ⑤-④Ⓐ gm.	⑦ Weight of treating chemical ③-④ gm.	⑧ Water absorbed by chemical ⑥/⑦, 1 lb H_2O, 1 lb chemical	⑨ Efficiency ⑧/Ⓑ %	⑩ Moisture ⑤/④ %
1. None - Sample in "as received" condition.	1W	0.679		0.658	0.021	Not applicable				3.2
	2W	0.860		0.840	0.020					2.5
	3W	0.821		0.801	0.020	for				2.5
	1K	2.940		2.805	0.135					4.8
	2K	2.887		2.761	0.126	"Treatments"				4.6
	3K	2.957		2.822	0.135					4.8
	1P	1.773		1.709	0.064	1 and 2				3.8
	2P	2.103		2.027	0.076					3.8
	3P	1.659		1.607	0.052					3.2
2. None - Sample exposed to 80 F - 80 % relative humidity air.	4W	1.228		1.078	0.150					13.9
	5W	1.474		1.295	0.179					13.8
	4K	4.889		4.057	0.832					20.5
	5K	5.284		4.424	0.860					19.4
	4P	3.068		2.537	0.531					20.9
	5P	4.270		3.512	0 785					21.6

Ⓐ. Equilibrium moisture content @ 80 F - 80 % RH. Varies with sample; 14 % for white pulp, 20 % for Kraft, 21 % for bulk pulp

Ⓑ. Equilibrium moisture content for pure chemical. Varies with chemical; 5.0 lb H_2O/lb NaOH, 2.8 lb H_2O/lb $Ca(Cl)_2$.

Table No. VI. Moisture Absorption by Chemically Treated Cellulose. (Cont.)

Treatment	(1) Sample number.	(2) Weight after exposure.	(3) Weight after treating and drying (@ 105c).	(4) Dry weight before treatment.	(5) Water absorbed (2)-(3), gm. or (2)-(4), gm.	(6) Water absorbed by chemical (5)-(4A), gm.	(7) Weight of treating chemical (3)-(4), gm.	(8) Water absorbed by chemical (6)/(7), 1 lb H_2O, 1 lb chemical	(9) Efficiency (8)/(B) %
3. Soaked in saturated sodium hydroxide solution. (NaOH)	6W	9.683	5.226	2.077	4.457	4.166	3.149	1.325	27
	7W	7.750	4.540	1.785	3.210	2.961	2.755	1.077	22
	6K	26.070	12.983	5.028	13.087	12.082	7.955	1.517	30
	7K	25.578	12.035	4.679	13.543	12.608	7.356	1.720	34
	6P	13.780	10.390	3.438*	3.390	2.658	6.952	0.382	8
	7P	17.263	11.001	3.587*	6.252	5.499	7.414	0.739	15
4. Soaked in 40 % (NaOH)	10K	18.911	8.426	2.805	10.485	9.924	5.621	1.78	36
	11K	19.849	8.951	2.761	10.898	10.345	6.190	1.67	33
	10W	5.599	2.068	0.658	3.531	3.439	1.410	2.44	49
	11W	7.197	2.652	0.840	4.545	4.428	1.812	2.44	49
	10P	17.940	7.185	1.709	10.755	10.397	5.476	1.90	38
	11P	17.766	7.844	2.027	9.922	9.497	5.817	1.63	33
5. Soaked in 20 % (NaOH)	12K	12.929	6.219	3.049	6.710	6.102	3.170	1.93	39
	13K	12.503	6.015	2.813	6.488	5.926	3.202	1.85	37
	12W			0.975					
	13W			0.954					
	12P	9.723	4.695	1.874	5.028	4.635	2.821	1.64	33
	13P	9.138	4.109	1.730	5.029	4.666	2.379	1.95	39
6. Soaked in 10 % (NaOH)	14K	6.904	3.735	2.458	3.169	2.678	1.277	2.10	42
	15K	5.563	3.443	2.619	2.120	1.597	0.824	1.94	39
	14W	1.683	1.134	0.876	0.549	0.427	0.258	1.69	34
	15W	1.456	0.986	0.775	0.470	0.362	0.211	1.75	35
	14P	3.593	2.124	1.207	2.469	2.216	0.917	2.41	48
	15P	4.980	2.388	1.496	2.592	2.278	0.892	2.55	51

* Some of sample dissolved and was lost.

Table No. VI. **Moisture Absorption by Chemically Treated Cellulose. (Cont.)**

Treatment	① Sample number.	② Weight after exposure.	③ Weight after treating and drying (@ 105°).	④ Dry weight before treatment.	⑤ Water absorbed ②-③ or ②-④, gm.	⑥ Water absorbed by chemical ⑤-④, gm.	⑦ Weight of treating chemical ③-④, gm.	⑧ Water absorbed by chemical ⑥/⑦, lb H_2O, lb chemical	⑨ Efficiency ②/⑧ %
7. Soaked in saturated calcium chloride solution. $(Ca(Cl)_2)$	8W	3.790	2.170	1.078	1.620	1.470	1.092	1.35	48
	9W	4.002	2.159	1.295	1.843	1.662	0.864	1.93	68
	8K	15.793	7.250	4.057	8.543	7.732	3.193	2.42	86
	9K	13.250	6.733	4.424	6.517	5.633	2.309	2.45	87
	8P	11.523	5.137	2.537	6.386	5.854	3.400	1.72	61
	9P	16.880	7.326	3.512	9.554	8.817	3.814	2.32	83
8. Soaked in 40 % $(Ca(Cl)_2)$	16K	9.315	4.993	2.822	4.322	3.758	2.171	1.63	58
	17K	11.060	5.411	2.695	5.649	5.110	2.716	1.88	67
	16W	3.154	1.841	0.801	1.313	1.201	1.040	1.16	41
	17W	3.214	1.741	0.863	1.473	1.353	0.878	1.54	55
	16P	8.751	4.019	1.607	4 742	4.405	2.412	1.83	65
	17P	8.618	4.193	2 023	4.425	4.001	2.170	1.84	65
9. Soaked in 20 % $(Ca(Cl)_2)$	18K	6.562	3.828	2.553	2.734	2.224	1.275	1.67	59
	19K	5.054	3.460	2.785	1.594	1.037	0.675	1.54	55
	18W	2.284	1.392	0.966	0.892	0.767	0.426	1.78	63
	19W	2.272	1.399	0.989	0.873	0.735	0.410	1.79	63
	18P	4.674	2.565	1.713	2.109	1.750	0.852	2.05	73
	19P	3.728	2.050	1.370	1.678	1.391	0.680	2.04	72
10. Soaked in 10 % $(Ca(Cl)_2)$	20K	4.451	3.046	2.557	1.405	0.894	0.489	1.83	65
	21K	5.074	3.334	2.753	1.740	1.190	0.581	2.05	73
	20W	1.017	0.855	0.736	0.162	0.059	0.119	0.50	17
	21W	1.225	1.017	0.896	0.208	0.083	0.121	0.69	24
	20P	3.406	2.059	1.653	1.347	1.000	0.406	2.45	87
	21P	3.534	2.050	1.590	1.484	1.151	0.460	2.49	88

Table VII
Adsorption Dehumidification of Protective Shelter
Summerlin Shelter - May 31, 1962

		Environmental Conditions in Shelter				Brine Production						Dehumidification Factors		
						Tray Unit #1			Tray Unit #2					
		T_{wb}	T_{db}	R.H.	E.T.	Volume	Weight	Ca Cl_2	Volume	Weight	Ca Cl_2	Cumulative Water Released	Cumulative Water Absorbed	Effectiveness
Date	Time	°F	°F	%	°F	ml	lbs	%	ml	lbs	%	lbs	lbs	%
5/24	1630	78.0	84.0	77	79.8									
5/24	1930	76.5	83.0	74	78.8							.11		
5/25	0830	75.7	82.0	75	78.0							5.84		
5/25	1020	78.0	84.0	76	79.8	565	1.84	49	847	2.52	38.5	6.51	2.48	38
5/25	1610	77.5	85.0	72	79.2	360	1.13	45	612	1.88	42	8.66	4.19	48
5/26	0915	78.5	83.0	82	79.6	750	2.24	39	868	2.42	30	14.85	7.25	49
5/27	1230	78.5	80.0	92	78.4									
5/28	0900	80.0	83.0	87	80.2	230	.61	24	298	.77	21	32.20	8.32	26
5/29	1100	80.8	83.0	90	80.5	28	.07		33	.08				
5/31	0900	80.7	83.0	90	80.5									

Table VIII
Environmental Data - Geometric Center, Broyles Shelter
July 30, 1962 - August 17, 1962

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
July	11:00 am	79.75	76.75	87	77.5	75.75
30	12:00	79.75	76	84		74
	1:00	79.25	76.25	87		75.25
	2:00	79.75	76.75	87		75.75
	3:00	80	77	87		76
	4:00	80	77.25	88		76.5
	5:00	80	77	87	79	76
	6:00	80	76.75	86		75.5
	7:00	79.75	76.5	86		75.5
	8:00	79.75	76.5	86		75.5
	9:00	80	76.5	85		75
	10:00	79.5	76.5	87		75.5
	11:00 pm	79.5	76.75	88	76	75.75
	12:00	79.75	76.75	87		75.75
July	1:00	79.75	76.75	87		75.75
31	2:00	79.5	76.5	86		75.5
	3:00	79.5	76.5	87		75.5
	4:00	79.75	76.75	87		75.75
	5:00	79.5	76.75	88	76	75.75
	6:00	80.25	77	86		75.75
	7:00	79.75	76.5	86		75.25
	8:00	79.75	76.75	87		75.75
	9:00	80	77	87		76
	10:00	80.5	77.5	87		76.5
	11:00 am	80	77.25	88	76.5	76.25
	12:00	80	77	87		76
	1:00	80.5	77.5	87		76.5
	2:00	80.25	77.5	88		76
	3:00	80	77.5	89		76.5
	4:00	80.25	77.25	87		76.25
	5:00	79.75	76.75	87	76	75.75
	6:00	79.75	77	88		76.25
	7:00	80.25	77.25	87		76.25
	8:00	80	77	87		76
	9:00	79.75	77	88		76.25
	10:00	79.5	76.5	87	76	75.5
	11:00 pm	79.5	76.5	87		75.5
	12:00	79.25	76.25	87		75.25

Table VIII (Cont.)
Environmental Data - Geometric Center, Broyles Shelter
July 30, 1962 - August 17, 1962

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Aug.	1:00 am	79.25	76.25	87		75.25
1	2:00	79.25	76.25	87		75.25
	3:00	79	76	87		75
	4:00	79	76	87		75
	5:00	79	76.25	88	75	75.5
	6:00	79.5	76.5	87		75.5
	7:00	79.25	76.5	88		75.75
	8:00	79.25	76.5	88		75.75
	9:00	79.75	77	88		76.25
	10:00	81.25	80	95		79.75
	11:00	84.5	79.25	79	81.25	77.25
	12:00	86	79.5	75		77
	1:00 pm	88	79.5	68		76.5
	2:00	87	79	70		76
	3:00	87.5	78.75	68		75.75
	4:00	87.5	78.75	68		75.75
	5:00	87.25	78	66	82	74.75
	6:00	87.5	77.75	65		74
	7:00	87.5	78.25	66		74
	8:00	86.75	78	68		74
	9:00	86.75	77.5	65		74.1
	10:00	86.75	77.25	65		73.6
	11:00	86.75	77	64	81.25	73.2
	12:00	85.5	76.5	66		72.5
Aug.	1:00 am	85.75	76.75	66		72.75
2	2:00	85.5	77	68		73.5
	3:00	85.5	77	66		72.5
	4:00	85.5	76.75	67		73
	5:00	85.5	76.5	66	80.5	72.5
	6:00	85.5	76.5	66		72.5
	7:00	86.5	77.75	67		74.4
	8:00	85.5	77	68		73.5
	9:00	86	77.5	68		74
	10:00	87	78	67		75
	11:00	89	79.5	66	83	76
	12:00	88.75	79	65		75.25
	1:00 pm	89	79.25	65		75.25
	2:00	88.5	78.5	64		74.5
	3:00	89	78.5	63		74.5
	4:00	89.5	78.5	61		74.5
	5:00	89	78.5	63	82.5	74.5
	6:00	89.5	78.5	61		74.5
	7:00	89.5	79.25	64		75.25
	8:00	88.5	78.5	64		74.5
	9:00	88	78.25	65		74.5
	10:00	88	78	64		74
	11:00	88	77.75	63	82	73.75
	12:00	87.5	77.25	63		73.25

Table VIII (Cont.)
Environmental Data - Geometric Center, Broyles Shelter
July 30, 1962 - August 17, 1962

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Aug. 3	1:00 am	87.5	77.25	63		73.25
	2:00	87.5	77	62		73
	3:00	87.5	77	62		73
	4:00	87.5	76.5	61		72.5
	5:00	87.25	76.5	62	81	72.5
	6:00	87.25	76.5	62		72.5
	7:00	88	77	61		73
	8:00	87.5	77.25	63		73.25
	9:00	88	77.75	63		73.75
	10:00	88.25	78.5	65		74.75
	11:00	88.25	78.75	66	82.5	75.25
	12:00	89	79	65		75
	1:00 pm	89.5	79.5	65		75.5
	2:00	88.75	79	65		75.25
	3:00	90.5	79.25	60		75.1
	4:00	90.5	79.25	60		75.1
	5:00	90.5	79.5	61	84	75.5
	6:00	89.5	79.5	65		75.5
	7:00	89.5	79.5	65		75.5
	8:00	89	79	65		75
	9:00	88.75	78.25	63		74.25
	10:00	88.5	78	63		74
	11:00	88.5	77.75	62	82	73.75
	12:00	88.5	77.5	61		73.5
Aug. 4	1:00 am	88.25	77.25	61		73.25
	2:00	88.25	77	60		72.75
	3:00	88	78	64		74
	4:00	88.25	77	60		72.75
	5:00	88	77	61	81.75	73
	6:00	88.25	77	60		72.75
	7:00	88.75	77.5	60		73.25
	8:00	88.5	77.75	62		73.75
	9:00	88.75	78.25	63		74.25
	10:00	89	78.75	64		74.75
	11:00					
	12:00	90	79.75	64		75.75
	1:00 pm	91	80.5	63		77
	2:00					
	3:00	91.5	79.75	60		75.75
	4:00	91.75	79.75	59		75.75
	5:00	90	78	58	82.75	73
	6:00	90	77.5	57		72.5
	7:00	90.5	78.75	59		74.4
	8:00	89	77.5	59		73
	9:00	88.5	77	59		72.5
	10:00	88.25	77	60		72.75
	11:00	88.5	77	59	82	72.5
	12:00	88.5	77	59		72.5

Table VIII (Cont.)

Environmental Data - Geometric Center, Broyles Shelter
July 30, 1962 - August 17, 1962

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Aug. 5	1:00 am	88.5	76.75	58		72
	2:00	88	76.5	59		72
	3:00	88	76	57		71
	4:00	87.75	76	58		71.25
	5:00	87.75	76.25	59	81	71.75
	6:00	88	76	57		71
	7:00	88.25	76.75	59		72.25
	8:00	88.25	77.25	61		73.25
	9:00	88.5	77.5	61		73.5
	10:00	89	78.5	63		74.5
	11:00	89.5	78.5	61	83	74.5
	12:00	90	79.5	63		75.5
	1:00 pm	90	79.25	62		75.25
	2:00	90.5	79.25	60		75.1
	3:00	91	79	59		75
	4:00	91.5	78.25	55		73.1
	5:00	91	78	56	83	73
	6:00	91.5	78	54		72.75
	7:00	91	78.25	57		73.5
	8:00	90	78.5	60		74
	9:00	90	78.5	60		74
	10:00	89.5	78.25	60		74
	11:00	89.5	78	60	82	73.5
	12:00	89.25	77.75	60		73.25
Aug. 6	1:00 am	89	77.5	59		73
	2:00	88.75	77.25	59		72.75
	3:00	88.5	76.75	58		72
	4:00	89.5	75	51		68.75
	5:00	90	73.75	46	80.75	66.5
	6:00	90.5	73	43		64.75
	7:00	91.5	73.5	42		65.5
	8:00	91.25	74.5	46		66.9
	9:00	91.5	76.5	50		70.5
	10:00	91	77.5	54		72
	11:00	91.5	77.75	54	83	72.4
	12:00	91.5	78.25	55		73.1
	1:00 pm	91.75	78.5	55		73.4
	2:00	92.5	78	52		72.5
	3:00	93.5	77.75	50		71.75
	4:00	93.25	79.5	55		74.5
	5:00	91.5	79.75	60	84.25	75.75
	6:00	91.5	80	61		76
	7:00	90	80.5	67		77
	8:00	89.5	79.5	65		75.5
	9:00	89	78.5	63		74.5
	10:00	89.25	79.25	65		75.25
	11:00	89	79	65	83	75
	12:00	88.5	78.75	65		75

Table VIII (Cont.)
Environmental Data - Geometric Center, Broyles Shelter
July 30, 1962 - August 17, 1962

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Aug.	1:00 am	89.75	76.5	54		71.25
7	2:00	91	74.5	46		67
	3:00	91.75	73.5	42		65.25
	4:00	92	73.5	41		65
	5:00	92	73	40	81	64
	6:00	92	73	40		64
	7:00	92.25	73	39		63.75
	8:00	92.5	74	41		65.5
	9:00	92.5	74	41		65.5
	10:00	91.5	73.5	42		65.5
	11:00	91.5	73.25	42	81	65
	12:00	92	79.25	57		74.5
	1:00 pm	92	80.5	61		76.5
	2:00	91.75	81	63		77.25
	3:00	91.5	81.75	66		78.75
	4:00	91.25	82.25	68		79.25
	5:00	90.5	82	70	85	79
	6:00	89.75	81.25	70		78.25
	7:00	89.75	81	69		78
	8:00	89.5	81.25	70		78.25
	9:00	89	80.75	71		77.75
	10:00	88.75	80.25	69		77.25
	11:00	88	80	70	83	77
	12:00	88.75	80	68		77
Aug.	1:00 am	88.75	80	68		77
8	2:00	88.75	79.75	67		76.75
	3:00	89	79.5	65		76
	4:00	88.25	79.5	68		76.5
	5:00	88.5	78.75	65	83	75
	6:00	89.75	77	56		72
	7:00	91.25	75.5	49		68.75
	8:00	90.75	76.25	51		70.25
	9:00	91	77	53		71
	10:00	88	74.75	54		68.75
	11:00	90.75	77.5	54	82.75	72.25
	12:00	90.75	79	59		74.8
	1:00 pm	91.25	80.75	63		77.25
	2:00	91	81	65		78
	3:00	91.25	81.25	65		78.25
	4:00	91	81	65		78
	5:00	92	80.25	60	84.5	76.25
	6:00	91.5	80	60		76
	7:00	91	81	65		78
	8:00	89	82.5	76		80.5
	9:00	88.5	81	72		78.5
	10:00	88.75	81.75	74		79.75
	11:00	88.25	82	76	84.5	80
	12:00	87.75	81.75	77		79.75

Table VIII (Cont.)
Environmental Data - Geometric Center, Broyles Shelter
July 30, 1962 - August 17, 1962

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Aug.	1:00 am	87.5	81.25	76		79.25
9	2:00	87.5	80.75	75		78.75
	3:00	87.5	80.5	74		78.5
	4:00	88	80.25	71		77.5
	5:00	88	79.5	69	83	76.5
	6:00	89.5	77	57		72
	7:00	91	75	48		68
	8:00	91.25	74.5	46		66.9
	9:00	91.75	74.5	44		67.1
	10:00	91	78.75	58		74.5
	11:00	90.25	79.5	62	83.75	75.6
	12:00	91	79	59		75
	1:00 pm	90.5	79.5	61		75.5
	2:00	90.75	80.5	64		77.1
	3:00	90	80.75	67		77.5
	4:00	90	81	68		78
	5:00	89	82.5	76	84.75	80.5
	6:00	88.75	83	78		80
	7:00	89.25	83.5	79		81.5
	8:00	87	81.5	79		79.5
	9:00	87	81.25	78		79.25
	10:00	86.75	80.75	77		78.75
	11:00	87	81.5	79	83.75	79.5
	12:00	87	81.25	78		79.25
Aug.	1:00 am	86.75	81.25	79		79.25
10	2:00	86.5	81	79		79
	3:00	86.5	81	79		79
	4:00	86.5	80.75	78		78.75
	5:00	86.25	80.5	78	83	78.5
	6:00	86	80	77		78
	7:00	86.25	80.5	78		78.5
	8:00	86.75	80.75	77		78.75
	9:00	87.5	81.75	78		79.75
	10:00					
	11:00	89	82.25	75	84.75	80.25
	12:00	88	82	77		80
	1:00 pm	88.5	82	76		80
	2:00	89	82.25	75		80.25
	3:00	89	82.75	77		80.75
	4:00	88.5	82	76		80
	5:00	88.75	82.5	77	84.5	80.5
	6:00	88	83	81		81
	7:00	87.5	82	79		80
	8:00	87.75	81.75	77		79.75
	9:00	87.5	81.75	78		79.75
	10:00	87.25	81.5	78		79.5
	11:00	87	81	77	83.75	79
	12:00	86.75	80.25	75		78.1

Table VIII (Cont.)
Environmental Data - Geometric Center, Broyles Shelter
July 30, 1962 - August 17, 1962

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Aug.	1:00 am	87	80.25	74		78.25
11	2:00	86.75	80	74		77.8
	3:00	86.75	80.25	75		78.1
	4:00	87	80.5	75		78.5
	5:00	87	80.75	76	85	78.75
	6:00	86.75	80.75	77		78.75
	7:00	87	81	77		79
	8:00	86.5	80.5	77		78.5
	9:00	87.75	81.5	76		79.5
	10:00	87.5	81.75	78		79.75
	11:00	87.5	81.75	78	84	79.75
	12:00	87.5	81.25	76		79.25
	1:00 pm	88	81.5	76		79.5
	2:00	88.75	81.5	73		79.25
	3:00	88.75	81.5	73		79.25
	4:00	88.75	81.5	73		79.25
	5:00	88.5	81.25	73	84	79
	6:00	87.5	80.75	75		78.75
	7:00	87.75	81	75		79
	8:00	87.5	81.25	76		79.25
	9:00	87.25	80.5	75		78.5
	10:00	86.75	79.25	72	82.25	76.6
	11:00					
	12:00	87.75	80	71		77.25
Aug.	1:00 am	88	79.75	69		76.75
12	2:00	88	79.75	69		76.75
	3:00	88	80	70		77
	4:00	88	80	70		77
	5:00	87.5	79.5	77	82.5	79.5
	6:00	87.5	79.5	77		79.5
	7:00	87.25	79.5	71		76.75
	8:00	87.25	79.5	71		76.75
	9:00	87.75	80.25	72		77.75
	10:00	88	80	70		77
	11:00	88	79.5	69	83	76.5
	12:00	88.5	80	69		77
	1:00 pm	89	80	68		77
	2:00	89	80.25	69		77.25
	3:00	89.5	80.25	67		77
	4:00	89.5	80	67		76.5
	5:00	89	80	68	83.5	77
	6:00	89	80	68		77
	7:00	88.5	80	69		77
	8:00	88.25	79.5	68		76.5
	9:00	88	79.5	69		76.5
	10:00	87.75	79.5	69		76.5
	11:00	87	78.5	69	82	75.5
	12:00	86.75	78	67		74.8

Table VIII (Cont.)

Environmental Data - Geometric Center, Broyles Shelter
July 30, 1962 - August 17, 1962

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Aug. 13	1:00 am	86.25	78	69		74.8
	2:00	86	78	70		75
	3:00	86	77.5	68		74
	4:00	85.5	77.5	70		74.5
	5:00	85.5	77	68	80.75	73.5
	6:00	85.5	77	68		73.5
	7:00	85.5	78	71		75
	8:00	86.5	78.75	71		75.9
	9:00	86	78.5	72		75.5
	10:00	87	78.75	69		75.75
	11:00	88	80.5	72	83.5	78
	12:00	88.25	80.75	72		76.25
	1:00pm	88.75	81	71		78.25
	2:00	89	81.5	72		79
	3:00	89.5	81.5	71		78.5
	4:00	89	81.25	71		78.5
	5:00	89	81	71	84	78
	6:00	89	81.25	71		78.5
	7:00	89	82	74		80
	8:00	88.25	81.5	75		78.75
	9:00	88.25	81.5	75		78.75
	10:00	88.5	81.75	75		79.75
	11:00	88.25	81.25	74	84	79.25
	12:00	87.5	80.5	74		78.5
Aug. 14	1:00 am	87.5	80 5	74		78.5
	2:00	87	80.5	75		78.5
	3:00	87	80	74		78
	4:00	87	79	70		76
	5:00	88	77.25	62	81.75	73.25
	6:00	88.5	76.25	56		71.1
	7:00	89	77.5	59		73
	8:00	88.75	79.75	67		76.75
	9:00	88.5	81	72		78.5
	10:00	89	81.75	73		79.5
	11:00	89	82	74	84.25	80
	12:00	89	82	74		80
	1:00 pm	89	82.25	75		80.25
	2:00	89.5	83	76		81
	3:00	89.5	83	76		81
	4:00	89.5	83	76		81
	5:00	89	83	78	85.25	81
	6:00	88.5	83	79		81
	7:00	88.5	83	79		81
	8:00	88.5	83.5	81		81.5
	9:00	88.25	83	80		81
	10:00	88.5	83.5	81		81 5
	11:00	88	82.75	80	84.75	80.75
	12:00	87.5	82	79		80

Table VIII (Cont.)
Environmental Data - Geometric Center, Broyles Shelter
July 30, 1962 - August 17, 1962

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Aug. 15	1:00 am	87.5	82	79		80
	2:00	87	81.5	79		79.5
	3:00	87	81.5	79		79.5
	4:00	87	81.25	78		79.25
	5:00	86.75	81	78	83.5	79
	6:00	86.5	81	79		79
	7:00	87	81.25	78		79.25
	8:00	87	81.5	79		79.5
	9:00	88	82.5	79		80.5
	10:00	88	83	81		81
	11:00	88.75	85	86	86.25	84
	12:00	89.25	85.5	86		84.5
	1:00 pm	89.25	85.5	86		84.5
	2:00	89.75	86.5	88		85.5
	3:00	90	87	89		86
	4:00	90	87.5	91		86.5
	5:00	90	87	89	87.75	86
	6:00	89.75	86.5	88		85.5
	7:00	90.5	87.75	90		86.75
	8:00	90.5	87.75	90		86.75
	9:00	90.5	88	91		87
	10:00	90.5	88	91		87
	11:00	90.5	88	91	88.5	87
	12:00	90.5	88	91		87
Aug. 16	1:00 am	90.5	88	91		87
	2:00	90.5	87.75	90		86.75
	3:00	90.25	87.75	91		86.75
	4:00	90.5	88	91		87
	5:00	90.5	88	91	88.5	87
	6:00	90.5	88	91		87
	7:00	90.5	88	91		87
	8:00	90.5	88	91		87
	9:00	90.5	88.5	92		87.5
	10:00	91	88.5	91		87.5
	11:00	90	87	89	87.75	86
	12:00	89.5	85.5	85		84.5
	1:00 pm	89.75	85.75	85		84.75
	2:00	90.25	85.5	82		83.9
	3:00	90.5	85.75	82		84.4
	4:00	90.25	85.5	82		83.9
	5:00	90	85.25	82	86.75	83.5
	6:00	89.75	85	82		83.25
	7:00	89.5	85	83		83.5
	8:00	89.5	85	83		83.5
	9:00	89.5	84.75	82		83
	10:00	89	84.5	83		83
	11:00	89	84.5	83	86	83
	12:00	88.75	84	82		82.25

Table VIII (Cont.)
Environmental Data - Geometric Center, Broyles Shelter
July 30, 1962 - August 17, 1962

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Aug.	1:00 am	88.5	83.5	81		81.5
17	2:00	88.75	83.5	80		81.5
	3:00	88.5	83	79		81
	4:00	88.5	83	79		81
	5:00	88.5	83	79	85	81
	6:00	88.25	83	80		81
	7:00	83.5	83	79		81
	8:00	85	82.5	79		80.5
	9:00	88.5	83	79		81
	10:00	88	82	77		80

Table IX
Environmental Data - Geometric Center, Central Stores Shelter
September 14, 1962 - September 25, 1962

A. Compiled from Dry Bulb and Dew Point Temperature
Minneapolis-Honeywell Dew Probe and Thermocouple

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Sept.	2:00 pm	83.75	81.5	91	82.75	80.75
14	3:00	88.5	86	92	86.5	85.25
	4:00	89	87.25	93	87.75	86.25
	5:00	90	87.5	91	88	87
	6:00	90	89	96	89	88.5
	7:00	90.25	89.5	94	89.75	88.75
	8:00	90.25	89.25	95	89.5	88.5
	9:00	90	89.25	97	89.25	88.75
	10:00	90.5	89.5	96	89.75	88.75
	11:00	90.5	89.5	97	89.75	89
	12:00	90.5	89.5	95	89.75	88.75
Sept.	1:00 am	90.75	89.25	92	89.5	88.5
15	2:00	90.25	89.5	97	89.5	88.75
	3:00	90.5	89.25	94	89.5	88.5
	4:00	90 25	89.5	96	89.5	88.75
	5:00	90.25	89.25	96	89.25	88.75
	6:00	90	89.5	95	89.5	88.75
	7:00	89.75	89.25	97	89.25	88.5
	8:00	90	89.5	97	89.5	89
	9:00	90.25	89.75	97	90	89.25
	10:00	90.75	90.5	98	90.5	90.25
	11:00	91	90.5	98	90.5	90.25
	12:00	91.5	91	98	91	90.5
	1:00 pm	92	90.5	95	90.75	90
	2:00	92	90.75	96	91	90.5
	3:00	91.75	91.5	99	91.25	91.25
	4:00	91.5	91.25	99	91	91.25
	5:00	91.5	91.25	99	91	91.25
	6:00	91.75	91.5	99	91.25	91.25
	7:00	91.5	91	98	91	90.75
	8:00	91.25	91.25	100	91	91.25
	9:00	91.5	91	99	91	91
	10:00	91.5	91.25	99	91	91.25
	11:00	91.5	91.25	99	91	91.25
	12:00	91.5	91	99	91	91

Table IX (Cont.)
Environmental Data - Geometric Center, Central Stores Shelter
September 14, 1962 - September 25, 1962

A. Compiled from Dry Bulb and Dew Point Temperature
Minneapolis-Honeywell Dew Probe and Thermocouple

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Sept. 16	1:00 am	91.25	91	100	91	91
	2:00	91.25	90.5	99	90.5	90.5
	3:00	91	90.75	99	90.75	90.75
	4:00	91.25	90.75	99	91	90.75
	5:00	91.25	90.5	98	90.5	90.25
	6:00	91	90.5	99	90.5	90.5
	7:00	91	90.25	99	90.25	90.25
	8:00	91.25	90.5	98	90.5	90.5
	9:00	91.25	91	100	91	91
	10:00	91.5	91.25	99	91.1	91.25
	11:00	91.75	90.5	99	90.5	91.5
	12:00	92.25	91	96	91	90.75
	1:00 pm	92.25	91.25	96	91.25	91
	2:00	92	91	98	91	91
	3:00	92.25	91	97	91.25	91
	4:00	92.25	91	95	91.25	90.5
	5:00	92.25	91	96	91.25	90.75
	6:00	92.25	91.5	97	91.5	91.25
	7:00	92.5	91.25	96	91.5	90.75
	8:00	92	91.75	99	92	91.75
	9:00	92.25	91.75	98	92	91.75
	10:00	92.25	92.25	99	92	92.25
	11:00	92.25	91.75	99	92	91.75
	12:00	92.25				
Sept. 17	1:00 am					92
	2:00	91.75	91.75	100	90.75	92
	3:00	89.5	89.5	100	89.25	91.25
	4:00	90.75	90.75	100	90.5	91.25
	5:00	90.25	90.25	100	90	89.25
	6:00	90.25	90.2	99	90	90.25
	7:00	90	90	100	90	90
	8:00	89.75	89.75	100	89.75	90.25
	9:00	91.5	91.1	99	91	91
	10:00	91.5	91.5	100	91.5	91.5
	11:00	92.5	91.4	97	91.5	91.25
	12:00	91.75	91.75	100	91.75	93.25

Table IX (Cont.)
Environmental Data - Geometric Center, Central Stores Shelter
September 14, 1962 - September 25, 1962

A. Compiled from Dry Bulb and Dew-Point Temperature
Minneapolis-Honeywell Dew Probe and Thermocouple

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Sept.	1:00 pm	92.25	92.25	99	92.25	91.75
17	2:00	93	91.5	96	91.75	91.25
	3:00	94	92.4	95	92.75	92
	4:00	94.75	92	91	92.5	91.25
	5:00	94.25	92.25	95	92.25	92
	6:00	93.25	93.25	100	93.25	93.5
	7:00	93	93	100	93	93.75
	8:00	93	93	100	93	93.5
	9:00	93	93	100	93	93.5
	10:00	92.75	92.75	100	92.75	94.25
	11:00	92.5	92.25	100		94.5
	12:00	92.5	92.5	100	92.5	94.25
Sept.	1:00 am	92.5	92.5	100	92.5	94.25
18	2:00	92.25	92.25	100	92.25	93.5
	3:00	92.25	92.25	100	92.25	93.5
	4:00	92.5	92.5	100	92.5	93.75
	5:00	92.25	92.25	100	92.25	93.5
	6:00	92.25	92.25	100	92.25	93
	7:00	92.25	92.25	100	92.25	93.5
	8:00	92.25	92.25	100	92.25	93.25
	9:00	92	92	100	92	94
	10:00	92.5	92.5	100	92.5	94.25
	11:00	92.5	92.5	100	92.5	94
	12:00	93	93	100	93	94.5
	1:00 pm	93	93	100	93	94.5
	2:00	92.75	92.75	100	92.75	94.75
	3:00	93.25	93.25	100	93.25	94.75
	4:00	93.5	93.5	100	93.5	95
	5:00	93.25	93.25	100	93.25	96.75
	6:00	93.75	93.75	100	93.75	97
	7:00	93.5	93.5	100	93.5	96.75
	8:00	93.5	93.5	100	93.5	96.75
	9:00	93.5	93.5	100	93.5	96.25
	10:00	93.25	93.25	100	93.25	96.25
	11:00	93.5	93.5	100	93.5	96
	12:00	93.5	93.5	100	93.5	96

Table IX (Cont.)
Environmental Data - Geometric Center, Central Stores Shelter
September 14, 1962 - September 25, 1962

A. Compiled from Dry Bulb and Dew Point Temperature
Minneapolis-Honeywell Dew Probe and Thermocouple

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Sept. 19	1:00 am	93.25	93.25	100	93.25	95.75
	2:00	93	93	100	93	95.5
	3:00	93	93	100	93	95
	4:00	93	93	100	93	95
	5:00	92.75	92.75	100	92.75	94.75
	6:00	93	93	100	93	94.5
	7:00	92.75	92.75	100	92.75	94.5
	8:00	93	93	100	93	94.25
	9:00	93	93	100	93	94.75
	10:00	93	93	100	93	95
	11:00	93.5	93.5	100	93.5	94.75
	12:00	93	93	100	93	95.25
	1:00 pm	93.25	93.25	100	93.25	94.75
	2:00	93	93	100	93	95.5
	3:00	93.25	93.25	100	93.25	94.75
	4:00	93.5	93.5	100	93.5	94.75
	5:00	92.25	92.25	100	92.25	94.25
	6:00	92.75	92.75	100	92.75	94.25
	7:00	92.5	92.5	100	92.5	94
	8:00	92.75	92.75	100	92.75	93.75
	9:00	92.25	92.25	100	92.25	93.5
	10:00	92	92	100	92	93.5
	11:00	91.75	91.75	100	91.75	93.25
	12:00	91.5	91.5	100	91.5	93.25
Sept. 20	1:00 am	91	91	100	91	92.5
	2:00	91	91	100	91	92.25
	3:00	91.25	91.25	100	91.25	92.5
	4:00	91.5	91.5	100	91.5	92.25
	5:00	91	91	100	91	92
	6:00	91	91	100	91	92
	7:00	90.5	90.5	100	90.5	91.5
	8:00	90.5	90.5	100	90.5	91.5
	9:00	91.5	91.5	100	91.5	91.75
	10:00	91.5	91.5	100	91.5	92
	11:00	91.75	91.75	100	91.75	92
	12:00	91.5	91.5	100	91.5	92.25

Table IX (Cont.)
Environmental Data - Geometric Center, Central Stores Shelter
September 14, 1962 - September 25, 1962

A. Compiled from Dry Bulb and Dew Point Temperature
Minneapolis-Honeywell Dew Probe and Thermocouple

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Sept.	1:00 pm	91.75	91.75	100	91.75	92
20	2:00	92	91.5	99	91.75	91.5
	3:00	91.5	91.5	99	91.5	91.25
	4:00	91.75	91.25	99	91.25	91.25
	5:00	91.5	91	98	91	91
	6:00	91.5	91	98	91	91
	7:00	91.5	91	98	91	91
	8:00	91	91	100	91	91.5
	9:00	91	91	100	91	91
	10:00	91	90.75	99	90.75	90.75
	11:00	91	90.75	99	90.75	90.75
	12:00	91	90.75	99	90.75	90.75
Sept.	1:00 am	90.75	90.75	100	90.75	90.75
21	2:00	90.75	90.5	97	90.5	90.25
	3:00	90.5	90.25	99	90.25	90.25
	4:00	90.5	90	98	90	90
	5:00	90.5	90	98	90	89.5
	6:00	90.25	89.75	97	90	89.25
	7:00	90	89.75	97	89.75	89.25
	8:00	90	88.75	96	89	88.75
	9:00	88.75	87.75	95	88	87.5
	10:00	86.75	86.75	99	86.75	86.5
	11:00	85.75	83.75	93	84.5	83.25
	12:00	85.5	81.5	84	83	80.25
	1:00 pm	85.75	80.5	81	82.75	79
	2:00	85.75	80.75	80	82.5	79.25
	3:00	85.5	81	84	83	79.75
	4:00	86	86	100	86	87
	5:00	86	81.5	84	83	80.25
	6:00	86.25	79.75	77	82.25	78
	7:00	88	80	72	83	77.75
	8:00	87	79.5	69	82.25	77
	9:00	87.25	78.25	69	82	75.25
	10:00	86.75	78.25	64	81.25	75.25
	11:00	87.5	77.75	66	81.75	73.75
	12:00	86.2	77.5	68	81.5	74

Table IX (Cont.)

Environmental Data - Geometric Center, Central Stores Shelter
September 14, 1962 - September 25, 1962

A. Compiled from Dry Bulb and Dew Point Temperature
Minneapolis-Honeywell Dew Probe and Thermocouple

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Sept. 22	1:00 am	86	77.25	71	81	74.25
	2:00	86	77.75	71	81.25	75
	3:00	85.75	77.75	71	81	75
	4:00	86	78	70	81.25	75.25
	5:00	87.25	78.75	69	82	75.75
	6:00	86.75	78.5	73	81.25	75.75
	7:00	86.25	78.5	67	81.75	76
	8:00	88.25	79	67	82.75	75.75
	9:00	86	78.5	72	81.5	76
	10:00	87.5	78.75	68	82	75.75
	11:00	88.5	79.75	69	83	76.75
	12:00	89.5	80.25	68	84	77.75
	1:00 pm	89	81.25	72	84.25	78.75
	2:00	89.75	81	69	84	78.25
	3:00	90	82.5	73	85	80.25
	4:00	90	83.5	76	85.5	81.25
	5:00	89.25	83.5	80	85.5	81.75
	6:00	88.5	81.25	74	84	79
	7:00	88.25	80.75	74	83.5	78.25
	8:00	87.75	80.5	75	83.25	78.25
	9:00	87.75	80.75	75	83.5	78.75
	10:00	86.5	79.75	76	82.25	77.75
	11:00	86.5	79.5	75	82.25	77.25
	12:00	85.75	79.5	76	82	77.25
Sept. 23	1:00 am	86.5	79.5	75	82.25	77
	2:00	87	80	75	82.75	77.75
	3:00	87.5	80	73	82.75	77.5
	4:00	86	79.5	76	82	77.25
	5:00	86.75	79.75	74	82.5	77.25
	6:00	87	80	75	82.5	77.75
	7:00	87.25	79.75	73	82.75	77.25
	8:00	87.75	80.25	73	83	77.75
	9:00	88.75	80.75	72	83.75	78.75
	10:00	89.5	82	74	84.5	79.75
	11:00	90	81.25	70	84.5	78.75
	12:00	89.5	81.75	74	84.5	79.5

Table IX (Cont.)
Environmental Data - Geometric Center, Central Stores Shelter
September 14, 1962 - September 25, 1962

A. Compiled from Dry Bulb and Dew Point Temperature
Minneapolis-Honeywell Dew Probe and Thermocouple

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Sept.	1:00 pm	90	82.25	73	85	80
23	2:00	90	81.25	69	84.5	78.5
	3:00	90	82.5	73	85	80
	4:00	90.5	82.75	73	85.5	80.25
	5:00	90.5	83.25	74	85.75	80.75
	6:00	90.25	82.75	74	85.25	80.5
	7:00	90.5	82.25	76	85.25	79.75
	8:00	89.5	80.5	68	84	77.75
	9:00	88.5	79.75	70	83	77
	10:00	88.25	79.25	68	82.75	76
	11:00	88.5	79.25	67	82.75	76
	12:00	88.25	79.25	67	82.75	76
Sept.	1:00 am	87.5	78.5	68	82	75.5
24	2:00	87.5	78.5	67	82	75
	3:00	87	78.25	68	82	75
	4:00	87.25	77.75	67	81.75	74.5
	5:00	87.5	77.75	66	81.75	74.5
	6:00	87	77.25	65	81.5	73.75
	7:00	87	77	65	81.25	73.5
	8:00	87.25	77.25	65	81.5	73.75
	9:00					
	10:30	83.75	77.5	77	80.25	75
	11:00					
	12:40	86	80.75	80	82.75	79.25
	1:00 pm					
	2:00	87.25	80.25	76	83	78.25
	3:00	88	81.25	75	83.75	79.25
	4:00	87.75	80.5	74	83.25	78.25
	5:00	88.5	82	77	84.25	80
	6:00	87.25	82.5	82	84.5	81
	7:00	87.5	81.25	76	83.5	79.5
	8:00	87.75	82.25	79	84.25	80.5
	9:00	87.75	82.5	80	84.25	80.75
	10:00	87.25	81.75	80	84	80.25
	11:00	87.5	81.75	78	83.75	80
	12:00	87.25	81.75	80	84	80.25

Table IX (Cont.)

Environmental Data - Geometric Center, Central Stores Shelter
September 14, 1962 - September 25, 1962

A. Compiled from Dry Bulb and Dew Point Temperature
Minneapolis-Honeywell Dew Probe and Thermocouple

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.	Dew Point
Sept. 25	1:00 am	86.25	81	82	83	79.75
	2:00	86.25	81	82	83	79.75
	3:00	86.25	80.75	80	83	79.25
	4:00	86	81	80	83	79.5
	5:00	86	80.75	80	82.75	79
	6:00	86.25	80.75	80	83	79.25
	7:00	86	81	80	83	79.5
	8:00	86.5	81	79	83	79.5
	9:00	88	82.5	80	84.5	80.75
	10:00	87.75	82.5	80	84.25	80.75
	11:00	88.5	83	79	85	81.25
	12:00	89.25	83.25	78	85.25	81.5
	1:00 pm	88.75	84.25	82	85.75	82.5
	2:00	89	84.5	82	86	83
	3:00	89	84.25	82	85.75	82.75
	4:00	89	84	80	85.5	82.25

Table IX (Cont.)
Environmental Data - Geometric Center, Central Stores Shelter
September 14, 1962 - September 25, 1962

B. Compiled from Wet Bulb and Dry Bulb Temperatures
Taken with Aspirating "Psychron"

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.
Sept.	10:00 am	90.2	87	87	87.75
15	2:00 pm	93.5	87.5	77	89.25
	3:55 pm	91	87.5	85	88.5
	6:20 pm	91.5	88.5	87	89.25
	8:15 pm	92	88	85	89
	11:25 pm	92	88	85	89
Sept.	1:30 am	89.4	86	86	87
16	3:10 am	90	87.1	88	87.75
	5:10 am	90.2	87	87	88
	7:10 am	89.9	86.8	88	87.75
	9:30 am	91	88	88	88.75
	12:15 pm	91.5	88.25	87	89
	2:10 pm	93	88	80	89.25
	3:05 pm	93	88	82	89.5
	5:16 pm	92	88	85	89
	7:20 pm	91.5	88.5	88	89.25
	10:30 pm	90.5	87.8	89	88.5
Sept.	1:10 am	90.8	87.6	88	88.5
17	3:10 am	89	87.5	94	87.75
	4:55 am	89	87	90	87.5
	7:10 am	89	86.6	88	87.25
	9:20 am	89.5	86	85	87
	1:29 pm	91	89	91	89.5
	3:37 pm	94.5	88	77	90
	5:30 pm	94	89.5	85	80.75
	8:30 pm	92	89.75	90	90.25
	11:30 pm	91.75	90	94	90.25
Sept.	1:10 am	90.3	89.8	98	89.75
18	3:10 am	90.6	89.4	96	89.75
	5:10 am	90.9	89.9	96	90
	7:10 am	89.9	89.4	98	89.5
	8:25 am	91	89.2	91	89.5
	1:50 pm	91.5	89.9	93	90.25
	3:20 pm	92.3	90.3	93	91
	6:15 pm	93	90.5	91	91
	9:20 pm	92.5	90.5	92	90.75
	11:30 pm	92	90	93	90.5

Table IX (Cont.)
Environmental Data - Geometric Center, Central Stores Shelter
September 14, 1962 - September 25, 1962

B. Compiled from Wet Bulb and Dry Bulb Temperatures
Taken with Aspirating "Psychron"

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.
Sept. 19	2:10 am	91.3	90	95	90.25
	4:10 am	91.4	89.6	92	90
	6:10 am	91.6	90	94	90.25
	9:15 am	91.5	89.5	92	90
	3:50 pm	92.8	90.2	90	90.75
	4:45 pm	91.5	89.5	92	90
	8:35 pm	91.25	89.25	92	89.75
	11:20 pm	90	89	97	89.25
Sept. 20	2:10 am	90.2	88.7	94	89
	4:10 am	90.2	88.1	91	88.5
	6:10 am	89.9	88	92	88.5
	9:35 am	90.5	88.1	90	88.75
	1:45 pm	91	88.4	90	89
	3:15 pm	91.1	87.3	85	88.25
	6:30 pm	91	87.75	87	88
	9:20 pm	90	86.25	86	87.5
Sept. 21	1:10 am	90.3	88	92	88.5
	4:10 am	89.4	86.5	89	87.25
	6:10 am	89.6	86.5	88	87.25
	8:30 am	89.5	85.8	86	87
	9:37 am	86.2	84.5	93	85
	10:20 am	85	82.5	90	83.5
	11:20 am	84.5	81	87	82.25
	1:45 pm	85	79	76	81.5
	3:40 pm	81.7	81.4	95	81.5
	5:30 pm	85.7	79.4	76	82
	8:45 pm	86.2	77.6	68	81.25
	10:45 pm	85.7	76.8	67	80
Sept. 22	2:10 am	84.9	75.4	65	79.75
	4:15 am	84.4	75.6	67	79.75
	6:10 am	84.1	76.7	72	80
	9:15 am	86.1	77.4	68	81.25
	12:15 pm	88.5	80	68	83.25
	3:45 pm	90	81.6	70	84.75
	5:30 pm	88	81.5	76	84
	9:15 pm	86.5	78.8	72	82
	11:45 pm	85.2	78.5	75	81.25

Table IX (Cont.)
Environmental Data - Geometric Center, Central Stores Shelter
September 14, 1962 - September 25, 1962

B. Compiled from Wet Bulb and Dry Bulb Temperatures
Taken with Aspirating "Psychron"

Date	Time	Temp. Dry Bulb	Temp. Wet Bulb	R.H.	E.T.
Sept.	2:15 am	85	78	74	81
23	4:15 am	85.5	78.5	73	81.5
	6:15 am	87.5	79.5	69	82.75
	9:45 am	89.2	81.4	72	84.25
	12:00 noon	90	81	68	84.25
	3:00 pm	90	82	71	84.75
	5:30 pm	87.5	79.6	70	82.75
	8:10 pm	87.6	78.4	66	82
	11:20 pm	85.6	77	68	80.75
Sept.	2:30 am	86.5	77	66	81.25
24	5:30 am	85	75.5	65	80
	1:20 pm	87.5	80	71	83
	6:15 pm	86.7	80.5	76	83
	8:30 pm	87	81.5	78	83.75
	11:30 pm	86.5	80.5	78	82.75
Sept.	1:30 am	86	80	77	82.25
25	5:10 am	83.5	78.8	80	80.75
	7:50 am	82.7	77.5	80	80
	9:50 am	88.7	81.5	74	84.25
	10:50 am	88	81.4	75	84
	1:30 pm	88.5	82.8	79	85
	3:30 pm	89	82.5	75	84.75